Inventory Optimization in an Aerospace Supply Chain

by

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Bachelor of Science in Mechanical Engineering
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Submitted to the Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirement for the Degrees of

Master of Business Administration
and
Master of Science in Engineering Systems

In Conjunction with the Leaders for Manufacturing Program at the
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Abstract

Strategic inventory management has become a major focus for Honeywell Aerospace as the business unit challenged itself to meeting cost reduction goals while maintaining a high level of service to its customers. This challenge has become particularly important as customers have steered their purchase decisions from focusing only on capability and quality to including cost performance as well. To do so, Honeywell Aerospace's Planning and Asset Management group is undertaking a three-year effort to re-engineer its inventory planning systems with the goal of increasing planner productivity, improving supply chain responsiveness, and reducing overall inventory.

This internship forms the building blocks of this strategy by leveraging existing software available in the industry and applying it to Honeywell's supply chain. Through two pilot programs with different supply chain designs, this internship analyzed the cost and benefit of transforming the company's inventory management strategy. In addition, this internship attempts to identify the challenges associated with such an enormous change, compare them with challenges with implementation in other industries in order to prepare management for full implementation across all product lines. These challenges range from leadership buy-in and information readiness to implementation feasibility both within Honeywell manufacturing and its suppliers.

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I would also like to thank my thesis advisors, LFM Program Director Don Rosenfield and Professor Debbie Nightingale, for their advice and support during my internship. Their two visits to Honeywell during my internship period provided me with much guidance and moral support.

Last, I would like to thank my family for their continuous support for my research.

Biographical Note

Billy Lo was born on December 4, 1978 in Hong Kong. Mr. Lo spent his early years in Hong Kong and then immigrated to the United States when he was nine. Mr. Lo attended the University of California, at Berkeley, graduating with high honors with Bachelor of Science Degrees in Mechanical and Materials Science Engineering.

Upon graduation, Mr. Lo worked for Intel Corporation as a Technical Program Manager in the Fab Capital Equipment Group. He spent his next four years managing various equipment suppliers such as Applied Materials and Novellus Systems and also conducted equipment selections for next generation wafer processing. Through his experience with Intel's complex supply chain network, Mr. Lo gained insight into the challenges suppliers face during the ups and downs of an industry cycle. As a result of these experiences, Mr. Lo applied to MIT's Leaders for Manufacturing Program to seek further exposure to the various operational challenges that companies face today.

Currently, Mr. Lo is a Leaders for Manufacturing Fellow at MIT, class of 2007. He may be contacted via email at billylo@sloan.mit.edu

Note on Proprietary Information

In the interest of protecting Honeywell International's competitive and proprietary information, all figures and data presented in this thesis have been changed, are for the purpose of example only, and do not represent actual Honeywell data.

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1 Introduction

The objective of this thesis is to present a case study for assessing the challenges involved in implementing strategic inventory placement models in an Aerospace Supply Chain. This thesis will provide an in-depth look into the practical considerations for implementing such a solution at a company as mature as Honeywell Aerospace. Pilot programs were conducted in two Product Centers, Engines and Avionics, within Honeywell Aerospace. These pilots allowed us to evaluate the feasibility of implementing such a model and to draw comparisons between similar implementations in other industries such as consumer products industry as well as comparing different products within the same industry. Professor Charles Fine, the author of *Clockspeed*, theorizes that different industries evolve at a different rate, depending in some way on its product clockspeed, process clockspeed, and organization clockspeed[i]. This study attempts to validate this theory and assess whether the speed of implementing inventory optimization varies across different industries as well. Inventory optimization has shown promising results in the retail, hi-tech, and consumer goods industry, but will it work in the aerospace industry?

The inventory optimization models were built using software called *PowerChain* that is licensed from Optiant Incorporation. Through these models, we were able to identify factors specific to the aerospace industry which could affect input variables and translate the resulting outputs into new opportunities for improving customer service while maintaining or reducing overall inventory levels.

1.1 Thesis Overview

The thesis proceeds as follows:

Chapter 1 provides the current landscape of inventory management at Honeywell Aerospace, and describes the motivation behind this internship.

Chapter 2 provides the drivers behind multi-echelon inventory optimization, the competitive landscape and industry offerings, and the fundamental approach behind Optiant *PowerChain*.

Chapter 3 describes the pilot program at the Engines Product Center. It describes the process from creation of the model to data analysis as well as the challenges involved with each stage of the pilot.

Chapter 4 describes the pilot program, at the Avionics Product Center. Specifically, the chapter discusses the result of this pilot program and how they compare with the results from the Engines pilot.

Chapter 5 draws general conclusions based on the research, which are applicable to the aerospace industry as well as specifically to Honeywell.

1.2 Honeywell International

Honeywell International (NYSE: HON) is a technology and manufacturing company with $27.7 billion in sales in 2005. Headquartered in Morris Township, New Jersey, Honeywell is comprised for four major business units: Aerospace, Automation and Control Solutions, Specialty Materials, and Transportation Systems. Aerospace is the largest sales segment with revenue of $10.6 billion in 2005 (see Figure 1).

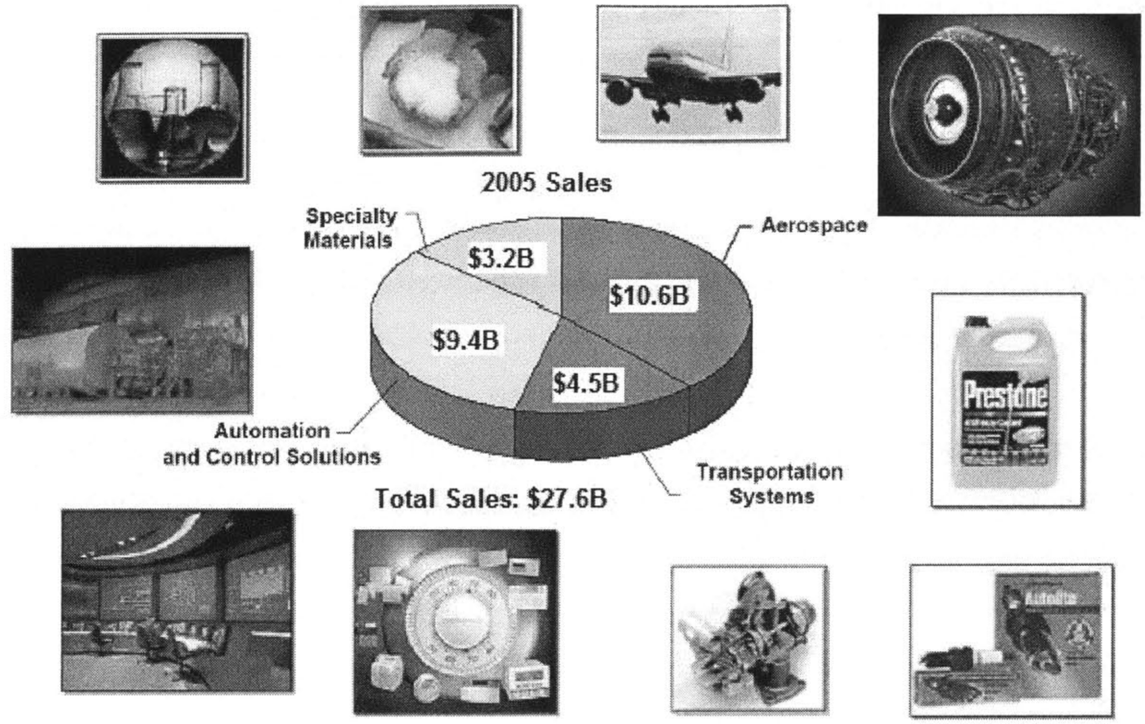


Figure 1: Honeywell's Revenue by Business Units[ii]

1.3 Honeywell Aerospace

Honeywell Aerospace is headquartered in Phoenix, Arizona. It employs 40,000 people worldwide and has 97 manufacturing and service sites across the globe.[iii] Honeywell Aerospace is a leading global provider of integrated avionics, engines, systems and service solutions for aircraft manufacturers, airlines, business and general aviation, military, space and airport operations. It has five major product centers: Guidance and Electric Systems (GES), Automated Aircraft Landing Systems (AALS), Engines Product Center (EPC), Avionics Product Center (APC), and Environmental and Thermal Systems (ETS). 60% of Honeywell Aerospace's 2005 revenue comes from these five product centers as shown in Figure 2.

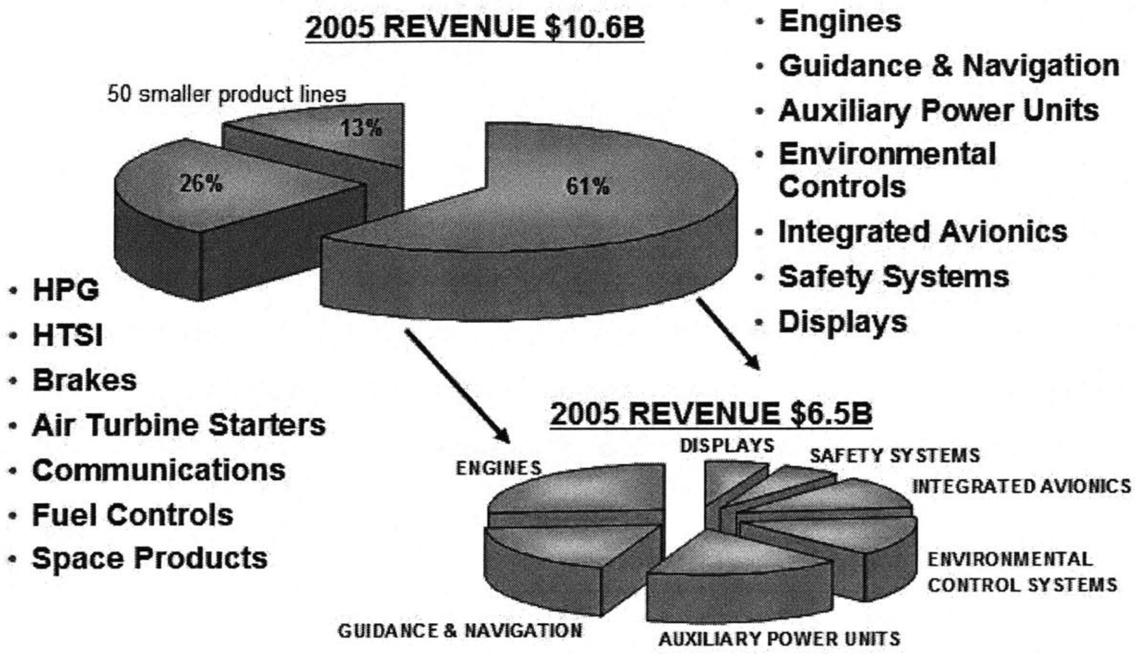


Figure 2: Honeywell Aerospace Revenue by Product Centers in 2005[iv]

1.4 Honeywell Aerospace's Reorganization and Five Initiatives

Honeywell Aerospace has recently restructured their organization to be more customer-oriented. Honeywell's management abandoned its previous structure of having over 10 business units and reorganized the business units into 3 groupings: Business and General Aviation, Air Transport Region, and Defense and Space. Through this restructuring, the organization has been able to assign single point of contacts for each of their customer segments. In addition to this restructuring, Honeywell Aerospace has identified five initiatives, which provide a focused set of goals to guide the business units. The five initiatives, taken from the Honeywell website, are Growth, Productivity, Cash, People and Enablers.

Of the five initiatives, this internship is primarily an effort to increase cash flow by re-evaluating and redesigning the current inventory management strategy. There is a direct relationship between how much inventory you want to hold and how well you are serving your customers. One method is to focus on reducing inventory to increase cash flow, however, that may result in inability to meet customer demand. As a result, there is an optimal balance between inventory holding and customer service. Currently, there is little structure in place to determine how much inventories Honeywell should hold. In fact, if you asked each business unit how much they are currently holding and how much they think their unit needs to hold if customer demand increases, you may get conflicting responses. This contributes to the current situation as captured in Figure 3. If you look at the month-to-month inventory as a percentage of sales over the past year, you will see that inventory can be as high as three times that of sales. As a result, management is determined to look at ways to better manage inventory so that the optimal balance between inventory and customer service can be achieved.

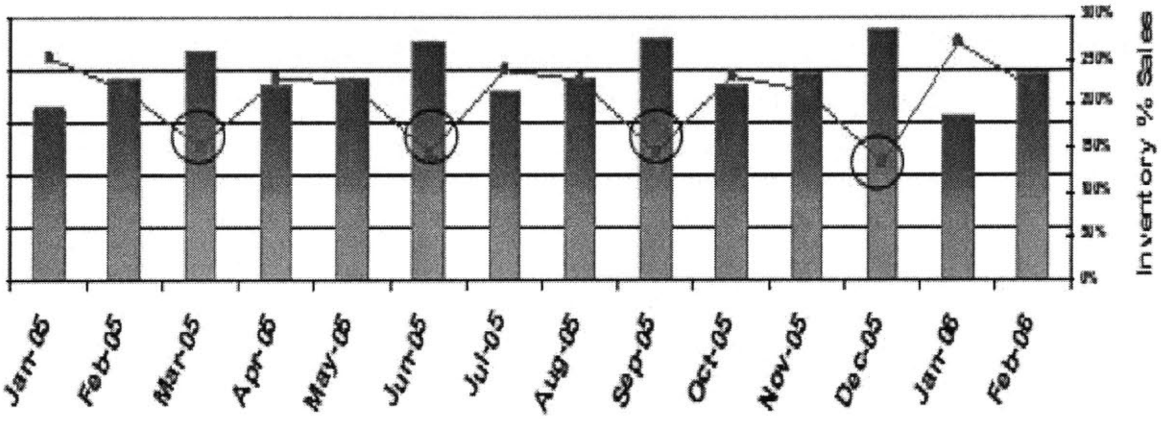


Figure 3: Inventory as a Percentage of Sales[v]

2 Literature Review

This chapter is broken into three sections. The first section will discuss the business drivers behind inventory optimization. The second section will provide the industry landscape for inventory optimization. The last section will focus on the history of Optiant Inc. as all the work done at Honeywell was through Optiant's inventory optimization software, *PowerChain.*

2.1 Multi-echelon Inventory Optimization

According to AMR Research, the inventory optimization software market was at $100 million in 2004, with a growth rate of between 30% to 50% predicted for 2005.[vi] Two main drivers lead this new market: increased demand and supply variability. Demand variability has been increasing over recent years as many companies have switched to become more customer focused. This switch has led to more customized solutions and an increase in the number of distribution channels. Similarly, supply variability has increased due to these new channels, especially through the increase in global outsourcing. While variability can be managed through the use of safety stock inventory, this solution can be costly and possibly send false demand signals upstream. Conversely, as inventory increases due to increased variability, inventory optimization becomes an even more attractive strategy to control cost without significantly impacting service level.

Three main business drivers help accelerate the need for inventory optimization. The first driver is increased globalization in manufacturing and exporting. Companies have reported an increase not only in lead-time (often doubled), but also in the variance (often 30% to 60% of the lead-time).[vii] Second, increased outsourcing makes it difficult for companies to see beyond its immediate value-stream (up or down), making inventory optimization a more important factor. For example, during an MIT Operations Strategy lecture, Professor Fine explained that the reason why Cisco Systems wrote off $2.25 billion in inventory after the dot-com bust was because Cisco failed to see beyond the variability from its immediate downstream customer. Cisco tries to position itself as a retailer by eliminating distributors in the value chain using direct ship methods from its contract manufacturers to final customer. While Cisco may seem like a retailer within the networking value-chain, when looking at the high-tech industry as a whole, Cisco is still an original equipment manufacturer. Therefore, when corporate spending began to decrease in early 2000, Cisco was not able to see the decline until its immediate customer stopped ordering. Unfortunately, by that time it was too late.[viii] Last, inventory ownership is being pushed to suppliers. Industry leaders are beginning to force suppliers to bear the burden of additional carrying cost for inventory needed to buffer variability. This forces suppliers at every level to hold some safety stock, which makes the overall supply chain very inefficient.

The impact of inventory mismanagement has become costly, which further drives the need for inventory optimization. Either companies tie up their cash in excessive inventory, or worst yet, they lose sales because the right inventory was not available to meet customer demand. In fact, according to the Council of Logistics Management's (CSCMP) 15th Annual Survey, in 2003, U.S. company total inventories were at a record high of $1.49 trillion, this is a $49 billion increase from 2002.[ix] These reasons have helped to initiate a new market of players interested in tackling inventory optimization based on a more global approach.

Even though this market is relatively immature, initial results have attracted some attention. Companies that have implemented inventory optimization have reported a Return on Investment (ROI) within weeks or within one to two months of implementation and order fill rates have increased by 2% to 13% due to improving levels of customer service.[x] This approach has enabled companies to transition from a "push strategy" based on their supply base to more of a "pull strategy" based on customer demand.

2.2 Landscape of Inventory Optimization Software

Currently there is no single dominant vendor in the inventory optimization space. Most Enterprise Resource Planning (ERP) vendors do not have multi-echelon inventory optimization capability and most Advanced Planning and Scheduling (APS) vendors have only emerging inventory optimization technology. Multi-echelon refers to supply chains with multiple locations for holding inventories. These locations, also known as stages, can be internal to a company or external to include a company's suppliers and distributors. For the purpose of this thesis, each part number within the bill of materials is considered a stocking location.

The inventory optimization industry is very fragmented led by specialty vendors such as Optiant, SmartOps, Logictools, Manugistic and ToolGroup. Consolidation is expected to happen in the upcoming years as giant Supply Chain Planning (SCP) vendors attempt to catch up to these specialty vendors by partnering with them. In fact, SAP has already begun partnerships with companies such as SmartOps and Logic Tools to integrate across various aspects of network optimization.[xi] Honeywell conducted an analysis to layout the various optimization techniques within a network design-- from strategic to analytical and tactical. Figure 4 shows a network optimization layout developed by at Honeywell.

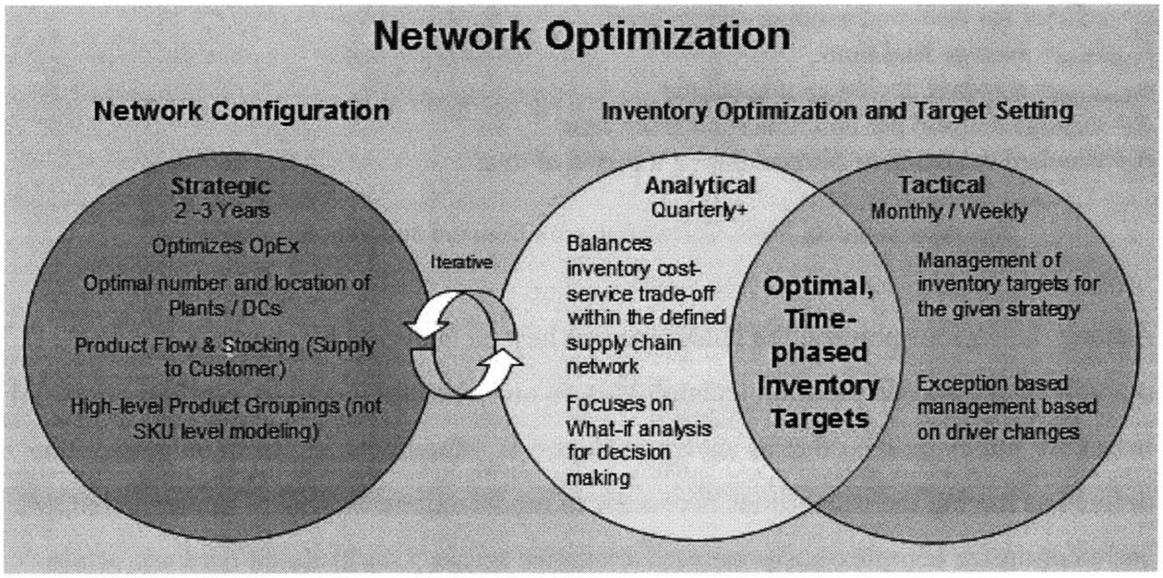


Figure 4: Network Optimization Software Overview[xii]

For the purpose of this thesis, the primary focus is to determine the state of inventory (Raw Material, Work-in-Process, and Finished Good) throughout the supply chain based on customer service level targets. While each company develops its own mathematical approach to calculating multi-echelon safety stocks, the factors relevant to calculating reorder points and safety stock levels are encompassed in the following equations:

$$s = \mathrm{L}^{e} \, x \, AVG + z \, x \, STD \sqrt{\mathrm{L}^{e}}$$

s = order point
L^{e} = echelon lead time, defined as the lead-time between the 1st echelon and the 2nd echelon plus the lead time between the 2nd echelon and its supplier, assuming inventory is not kept at the 2nd echelon. In general, it is the lead-time to the next location where safety stock is held.
AVG = average demand across all customers of a given item
STD = standard deviation of (aggregate) demand across all customers of a given item

Equation 1: Reorder Point for Echelon Inventory Position[xiii]

The above equation assumes no variation in lead-time. In general, for a lead-tim with variation, the safety stock equation is as follows.

$$ss = \mathrm{z} \, x \sqrt{(\mu_{\text{Lead Time}} \, x \, \sigma_{d}^{2} + \mu_{d}^{2} \, x \, \sigma_{\text{Lead Time}}^{2})}$$

ss = safety stock level
z = z factor for the corresponding service level
$\mu_{\text{Lead Time}}$= average lead time
$\sigma_{\text{Lead Time}}$= standard deviation of lead time
μ_{d}= average demand per unit time for a given time
σ_{d}= standard deviation of demand during a period of time

Equation 2: Safety Stock Calculation with Demand and Supply Variability[xiv]

Among the various players, the landscape can best be analyzed by charting manufacturing and distribution technologies on one axis and inventory configuration and inventory policy on the other as shown in Figure 5. Manufacturing technologies can be defined as having the capabilities necessary to model extensive bills of materials (BOM) and to optimize complex postponement strategies across a multi-tiered network, while accounting for supply variances within the network. Distribution technologies focus on service levels by both the type of customer and inventory classification by analyzing the right inventory levels based on demand and supply variability within a multi-tiered network[xv]. And according to AMR research, SmartOps is best positioned for the Supply Chain Platform in the future because traditional ERP/APS solutions lack true optimization functionality at a tactical level.

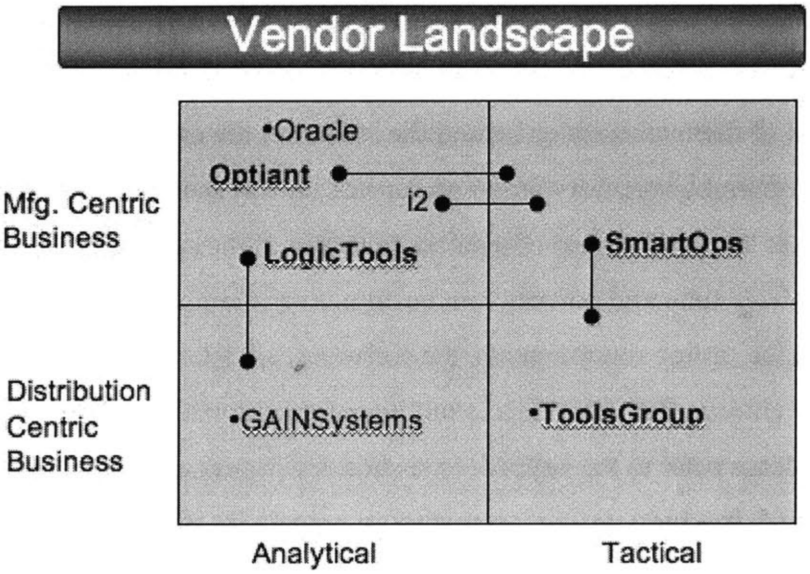
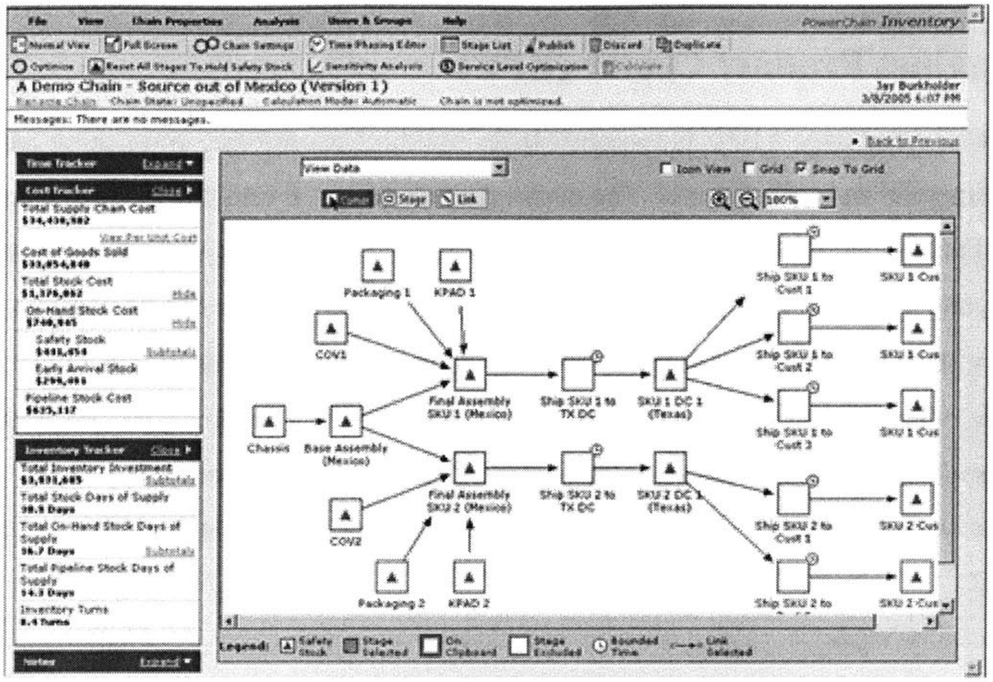


Figure 5: Landscape of Inventory Configuration and Inventory Policy Vendors[xvi]

2.3 Optiant Inc. - *PowerChain*

During their research at MIT and the Sloan School of Management, Dr. Sean Willems and Professor Stephen Graves developed a framework for modeling safety stock in a supply chain that is subject to demand or forecast uncertainty. Their framework assumed the supply chain as a network, that demand is bounded with a guaranteed service time between stages and that each stage in the supply chain operates under periodic review.[xvii] This assumption enabled them to develop an optimization algorithm for the placement of strategic safety stock for supply chains that can be modeled as spanning trees. This algorithm led to the founding of Optiant Inc. in 2000. Optiant, which is headquartered in Burlington, MA, is a privately held company with approximately 41 employees. Using this algorithm, Optiant's *PowerChain* Inventory software provides probabilistic inventory configurations and policy determinations across a complex multi-tiered network in a user-friendly interface. This software has been in the consumer products, life science, high tech and electronic, and chemical industries.[xviii]

PowerChain establishes optimal inventory targets and policies in order to reduce overall inventory cost, while increasing service levels. This is achieved through maximizing customer service levels while minimizing inventory investment, determining inventory levels by considering supply and demand uncertainty, and determining inventory locations by trading off balancing cost and lead-time considerations. Without going into too much detail of the mathematics behind the software, the crux of *PowerChain*'s approach is to optimize inventory based on service time at specific locations. The software looks at the service time of a particular stage of the supply chain with regards to its upstream service time and downstream customer or subsequent stages quoted lead-time. Through the timing requirements, the software can determine which nodes require safety stock inventory. For more details on the optimization algorithm and its underlying assumptions, please refer to the references section for papers and dissertation written by Willems[xix]. Much has been written on inventory models for multi-stage supply chain with uncertain demand. Of the published work, Willems research is most related to and is an extension of the works by Simpson (1958), who modeled supply chain as a serial network, Inderfurth (1991, 1993), Inderfurth and Minner (1995) and Minner (1995), by treating networks as spanning trees[xx]. However, the resulting model differed dramatically from these researches due to different assumptions used for the demand process and different constraints on service levels within the supply chain. For example, the model assumed that within this multi-stage network, each stage is considered a potential location for holding a safety stock inventory of the item processed at the stage. The arcs connecting these stages assumes a scalar factor to represent the number of units of the upstream component I that are required for downstream unit j. It also assumes that for each stage, the production lead-time is deterministic.[xxi] On the demand process, the model assumes that external demand occurs only at stages that have no successors and that it is bounded.[xxii] Figure 6 provides a screenshot of *PowerChain's* user interface. All key *PowerChain* terminologies are captured in the glossary of Chapter 6 of this thesis.



A Demo Chain - Source out of Mexico (Version 1)

Chain State: Unspecified Calculation Mode: Automatic Chain is not optimized.

Jay Burkholder
3/8/2005 6:07 PM

Messages: There are no messages.

Figure 6: Screenshot of Optiant *PowerChain*

3 Engines Product Center (EPC)

Honeywell Aerospace's EPC is responsible for building, assembling and testing engines for commercial and military use. The division can be divided into three primary family codes: 1) Commercial Propulsion, 2) Commercial Auxiliary Power Units (Commercial APUs), and 3) Military & Helicopter, Industry & Marine (Military APUs). Within each division, there are numerous product lines designed to serve customer needs. For example, within the Commercial Propulsion Group, there is a product line dedicated to Business Aviation where engine models 731-xx, ATFx, and CFE-xxx are grouped together, while a separate product line is dedicated to Turbo Propulsion as shown in Figure 7.

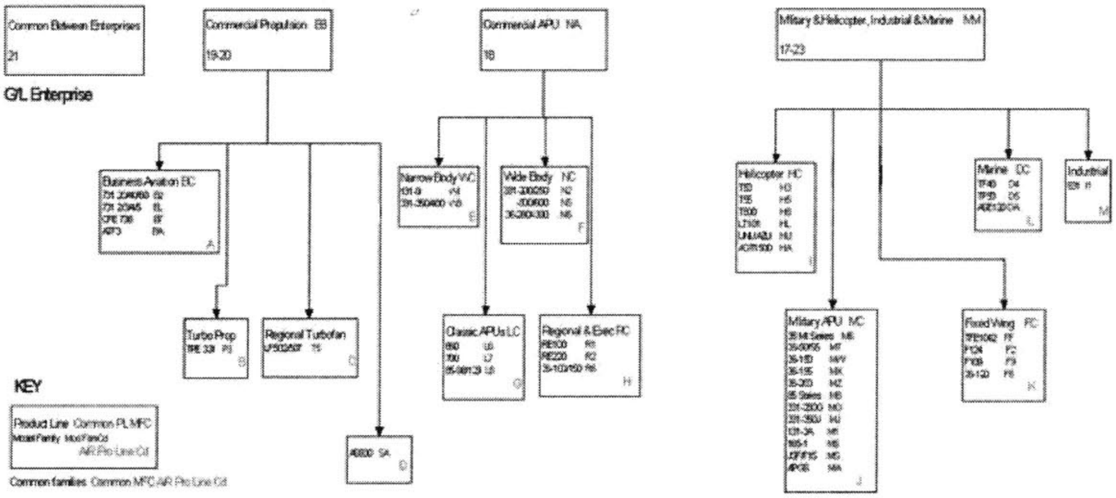


Figure 7: Engines Product Line Model Family Codes

Grouping the manufacturing organization vertically not only helps design the manufacturing process flow; it also helps align the divisions with their respective customers so that they become more customer oriented with increased ownership and accountability. Interestingly, the sourcing group is organized horizontally according to the process type or raw material such as forging and casting, metals, and electronics. This makes sense from a buyer's perspective since this structure increases the buyer's power over the limited number of suppliers available to supply the materials.

Nevertheless, this encourages the manufacturing group to work with sourcing to make sure the "right" material is available to build the "right" products.

Complicating the matter, EPC has 3 manufacturing sites each known as a Center of Excellence (COE) where they make gear line components, rotating and circular components, as well as casing structures. Because of this, when the Material Production System schedules an engine to be built, parts from suppliers are shipped to the various COEs as well as the Final Assembly and Test facility. These parts are machined and partially assembled within each COE and then sent to the Assembly and Test Facility for final assembly. Since a typical engine has approximately 1,100 parts can be supplied from over 100 suppliers and 12 Honeywell factories, the likelihood that all parts are available at the start of the build is almost zero.[xxiii] As a result, on-time customer delivery suffers and inventory swells as buyers order more parts to prevent their parts from being the limiting factor. In fact, a Leaders for Manufacturing intern, Andrea Jones, conducted a study last year to analyze the relative On-Time-To-Request (OTTR) performance across Honeywell's various Engine Segments (Figure 8). In her thesis, *Using Lean Enterprise Principles to Drive Quality and On-Time Delivery to Customers*, Andrea points out that the reason why the OTTR performance for Commercial Engines was significantly worst than for the other product families is because of the complexity of design and longer lead-time of materials of commercial engine products. The purpose of this internship is to seek a method to optimize the material flow of a commercial engine from an inventory standpoint, as well to understand the critical stages of building an engine in order to reduce the effective lead-time of materials involved in commercial engine products.

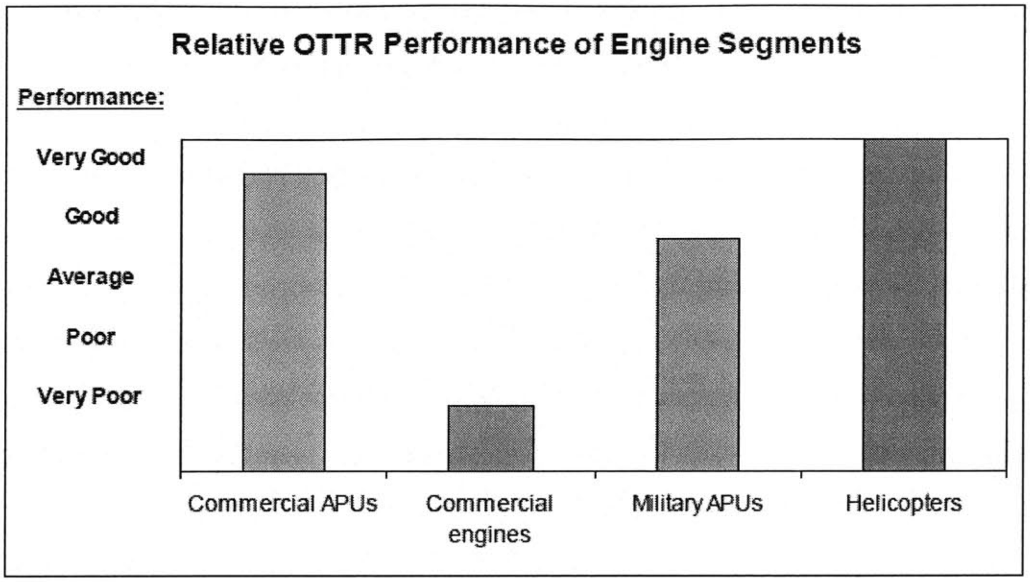


Figure 8: Relative On-Time to Request Performance of Engine Sales Segment[xxiv]

3.1 131-9 Auxiliary Power Unit Overview

The initial intent of this pilot is to apply the Optiant *PowerChain* multi-echelon strategic placement model to the 731-xx engines product line within the Commercial Engines Family. However, due to concerns over the fact that this product line was in the midst of implementing kanban systems, the pilot team decided to shift it's focus to a more stable product, the 131-9 (APU). When looking at the volume of this product and the annual cost of goods sold figures, the 131-9 APU was a very suitable candidate to conduct this pilot.

The 131-9 APU is essentially a small jet engine that provides compressed air for starting main engines and air conditioning and electrical power on the ground or in flight (See Figure 9). It is designed for single-aisle aircrafts and its primary purchasers are Airbus and Boeing. Therefore, there are two main end-items for this product line with code names 131-9A to designate Airbus, and 131-9B to designate Boeing.

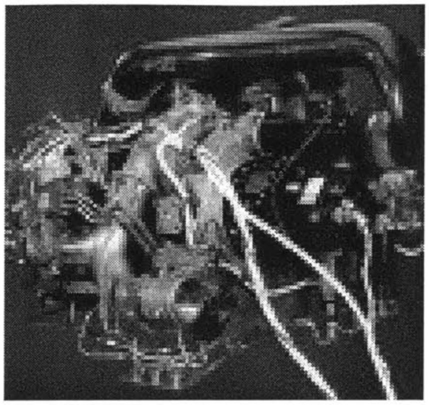


Figure 9: 131-9 Auxiliary Power Unit[xxv]

The 131-9 APU has a five-level BOM with four major assemblies: Plumbing and Electrical Assembly, Power Section Assembly, Gear Box Assembly, and Engine Kit Plus. A total of 468 part numbers go into this unit with 407 parts made by suppliers and 61 parts made internally by Honeywell. Of the 468 parts, 202 of them are shared between the 131-9A and 131-9B models and 57 components are shared across other product lines.

The cumulative lead-times for the 131-9A and 131-9B models are over a year. In addition to supplying the end-items to Original Equipment Manufacturer (OEM) customers, the COEs and the Assembly and Test Facility are also responsible for delivering parts to the AfterMarket Services (AMS) division. For this product, over 270 parts are used by the Repair and Overhaul group within AMS. This creates additional demand streams with different demand profiles to complicate the planning process.

3.1.1 High-Level Material Flow

Before building the inventory model, a simple diagram was built to understand the material flow-through of this product (See Figure 10). From the figure, it is easy to identify the number of purchase parts which go into each COE and, in turn, the numbers of parts that go back into the COE for further assembling and or to the Final Assembly and Test Facility stage. This model helped simplify the BOM from as many as 468 nodes to seven specific nodes and it will become essential during the analysis and implementation phase as it helps highlight trends and common high-risk areas.

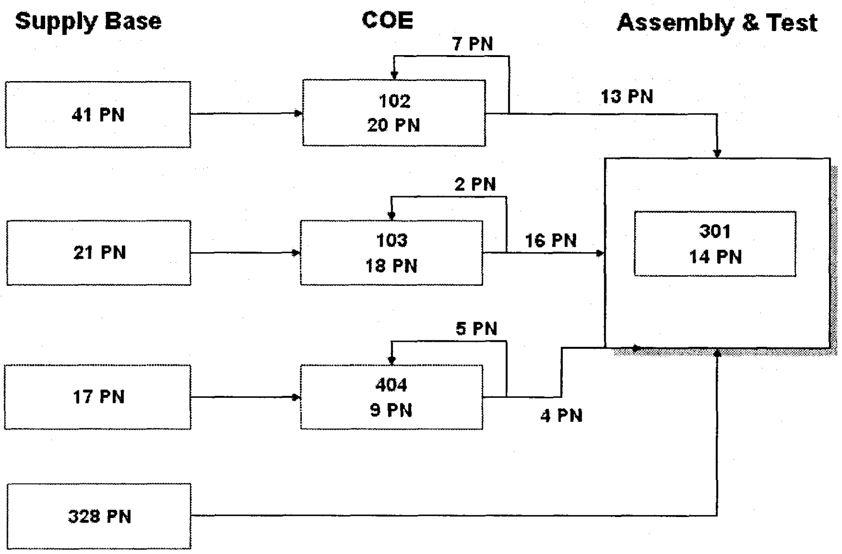


Figure 10: Material Flow Diagram for 131-9 APU

3.2 Building the Model

A large number of inputs are required for building this Model, including the associated part numbers, the BOM structure, the value added cost, the variability in demand orders and supply deliveries etc. These inputs were gathered with relative ease with the help of an Excel macro that was written several years back when another product group within Honeywell evaluated *PowerChain*. The benefit of this macro is that the BOM structure and associated information can be automatically pulled from an internal database and formatted into the *PowerChain* template for an easy upload. While this macro helped reduce a lot of data entry time, it also made the Model more inflexible. Because it built the framework from the bottom up, with each "stage" represented by a part number, it was unable to build a framework that reflected the high-level material flow diagram as shown in Figure 10. As a result, Honeywell's management had to make a decision on whether to use the macro and build off of what was accomplished previously or to build the Model from scratch. They made a decision to build the Model to be as complex as possible but to reduce this complexity through the results and an evaluation of the sensitivities of the input parameters.

3.2.1 The Model

Figure 11 shows the completed Model for the 131-9 APUs. The squares represent a part number and the links represent the reporting structure of the BOM. Each link has an entry option to capture the quantity used per downstream assembly. The 131-9B BOM was first built as captured by the dotted square in the top half of Figure 13. The end-item is located to the far right and the resulting five-level BOM is captured within each column of part numbers. Notice that part numbers within each level of BOM are stacked on top of each other to make the Model simpler to read. Parts that are made by Honeywell but not within the EPC were pulled out and captured by the circles. These parts include valves and generators that are delivered from independent manufacturing sites that service not only EPC but also other product centers including the AMS division.

The next step is to build the 131-9A BOM. Since the common parts have already been built through the 131-9B BOM, the unique parts were the only components added to the BOM structure as captured by the dotted box in the lower half of Figure 11. Lastly, the demand nodes were added. The OEM demand was added directly to the 131-9AB end-item nodes. The AMS demand nodes, on the other hand, were added as phantom nodes as denoted by the squares within the dotted boxes at the top and bottom of Figure 11. As shown within Figure 11, there is AMS divisional demand across every level of the BOM.

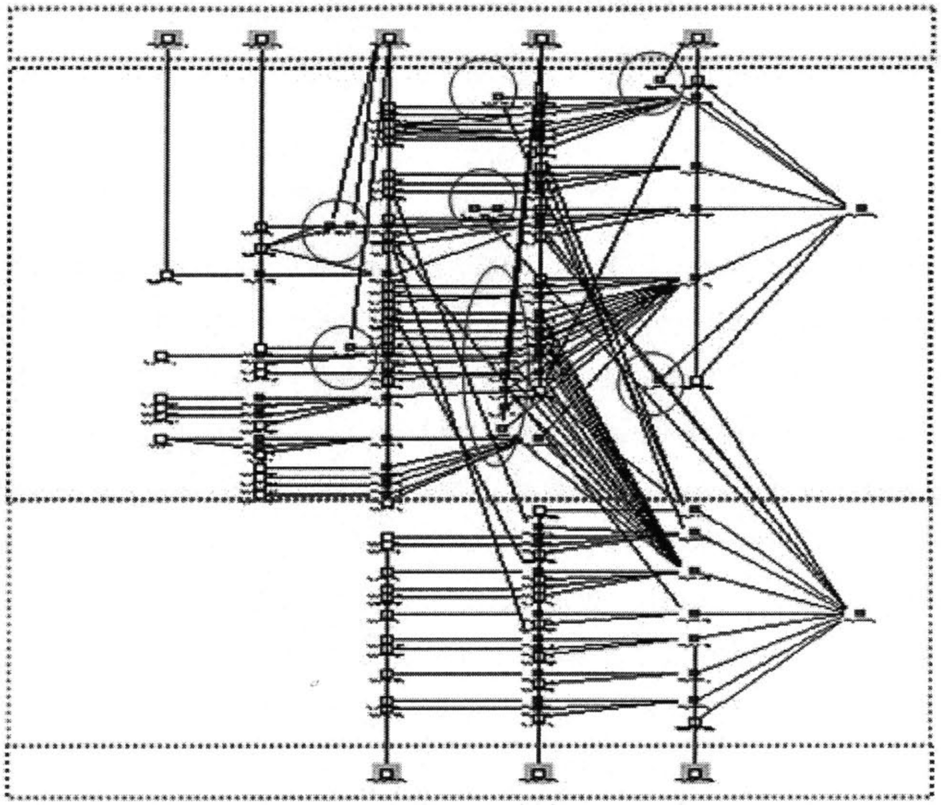


Figure 11: 131-9AB Inventory Optimization Model

3.2.2 Assumptions Applied to the Model

Several key assumptions were made to complete this Model. The complete list of assumptions is set forth in Table 1. While some assumptions were made to align with Honeywell's corporate policies such as their Order Policy, other assumptions were made pursuant to team decisions. For example, the Model used a warm start lead-time instead of a cold start lead-time for this product line. Warm start lead-time is the lead-time required to place an order, setup the machine, run production, and shipment. Cold start lead-time on the other hand adds extra steps in retooling, first article inspection, and finish test. Cold start lead-time is used for new products or products that have not been in production for a while. For this product, it has such high volumes that the machine setup time and quality inspection which are part of the cold start routine do not apply here. In addition, the lead-time variability only captured the variability with late deliveries. There are two reasons for this result: 1) Honeywell has a policy that it does not receive materials more than five days before the request date, and 2) the Model should not recommend safety stock to buffer for the variability that arises from parts delivered early.

Assumptions Applied to Model	
Lead-time	Used warm start lead-time
Lead-time variability	Variability of on-time and late receipts delivery against the warm start lead-time
Cost	Value-Added cost plus burden rate
Demand	Forecasted out 9 months to calculate average and standard deviation of demand
Customer	105 M Days to Boeing and 90 M Days to Airbus at 95% Service Level
Yield	Used first pass yield data. Additional 3 days for re-work parts
Review Period	5 Days of Supply (DOS) for A's, 20 DOS for B's, and 60 DOS for C's
AMS Demand	Turn-around time from OEM to AMS is 5 days

Table 1: Assumptions for 131-9 Model

3.3 Challenges with Building the Model

Even though most of the inputs were automatically uploaded into Power Chain, issues with the data created significant challenges during the building phase.

3.3.1 Challenge #1: Bill of Materials

The challenge with the BOM is that it is not always accurate. While building the Model, there were phantom parts with lead-time values associated with them. When validating this with manufacturing group, it appears that the technicians understood the product so well that they did not really refer to the BOM as the building reference. As such, the BOM became outdated and there was no defined process to maintain it. In addition, the sourcing group constantly looked for opportunities to reduce material cost through cross qualification. Because of this, there are many parts that are either dual sourced or have alternative approved suppliers. Capturing the lead-time and lead-time variability for one part from two suppliers within *PowerChain* became very difficult. This creates a maintenance challenge for the Model as the product is constantly evolving and there is no robust process to communicate these changes.

Another challenge with the BOM involves shared parts across other platforms. For the 131-9 APU Model, 57 parts are being used in other products. Therefore, if the Model suggests a minimum safety stock quantity, this number may be suboptimal since it did not optimize across the supply chains of the other platforms. For this Model, dummy demands were created to capture the real usage rates of the parts. While the safety stock recommendations may have been suboptimal, the team decided that it was still a positive step towards having the right levels of inventory at the right locations.

3.3.2 Challenge #2: Cost

Cost is one of the most critical inputs to the Model. For the most part, the cost data was quite up to date within Honeywell systems. However, most of the costs were measured at cumulative cost and not at value-added cost. Therefore, to avoid double counting within *PowerChain*, it was critical to understand what value was added to each part during the manufacturing cycle and to make sure that there is no cost associated with phantom or reference parts. The phantom and reference parts are structured into the BOM to help technicians build the engine easier and have cleaner documentation.

Another scenario in which measuring cost became a challenge for Honeywell was for parts under a shared revenue contract. Shared revenue contracts allow Honeywell to defer payment for materials and to only pay the suppliers when there is a demand for certain items and after customers have paid. Through these contracts, Honeywell was able to lower its inventory cost while encouraging suppliers to develop a good relationship with Honeywell. While this is a good supply chain policy, it does affect the accuracy of the cost data for the part sold. Because parts are under this shared revenue policy, parts stocked in the warehouse have dummy values attached to them. These values are typically low because that is how much Honeywell paid. These prices also fluctuate as a function of the volume of sales over time and how the contract agreement is structured to account for volume discounts. Because of this, determining the actual value without knowing the final sales volume made validating the cost data even more challenging. Without knowing its actual cost, the Model would take its low dummy value into the calculation and, more often than not, would suggest holding safety stock.

3.3.3 Challenge #3: Forecasting

Honeywell uses their Material Production System (MPS) to provide forecasts and track firm Purchase Orders (POs). Typically, the system forecasts demand over a two-year lookout to begin ordering parts that have lead-time over 365 days. While materials are being purchased and planned two years in advance, the customers can place orders up to 90 days before delivery. Given this discrepancy in the period to place orders , disruptions can occur when customers add or drop orders last minute or even within the contractual lead-time. As a result, the MPS is constantly updating information and it becomes very difficult to measure forecast calculation errors in the system. Even when there is a calculated error, it is difficult to determine whether this error came from forecasting or because manufacturing did not have the capacity to deliver the order in time. Because of this, the Model used average demand and variability within demand to mimic the forecast error that would be seen within the MPS system.

3.3.4 Challenge #4: Supplier Delivery

There are two major challenges involved in measuring supplier delivery performance. The first challenge is to understand the true root cause of supplier performance issues. In this Model, supplier performance was measured over a one-year period to reduce the day-to-day and week-to-week noises within the system. The early deliveries were removed from the calculation to avoid having them average out the late deliveries, resulting in a false picture of the true lateness of the supplier performance. The challenge with the one-year measurement approach is that seasonality effects may not be accounted for and the solution may assume that the variability due to seasonality is part of normal business operations. For instance, this approach may not account for end of quarter sales, end of the year sales, or even end of the month sales, which could affect the amount of inventory needed to service those periods.

In addition, this approach can overlook the one-time quality events that may have taken place within the last year but have since been resolved with other means besides using safety stock. For example, Figure 12 shows the receipt history of a part that went through a quality excursion. Prior to this excursion, the delivery performance of this part was either on-time or late on average for five days. However, because of an excursion, these parts have been delivered, on average, 25 days late. If the Model uses this variability, then it would suggest holding a higher safety stock. However, as demonstrated in Figure 12, the excursion has been contained and the delivery performance seems to be improving, thus the Model should not recommend maintaining safety stock for this "troubled" part. Accordingly, to prevent buffering for one-time events, it is necessary to look at the individual receipt history of each part and determine whether such variability can exist in the future. Doing this for all 468 parts of the 131-9 Model, however, would be a daunting task.

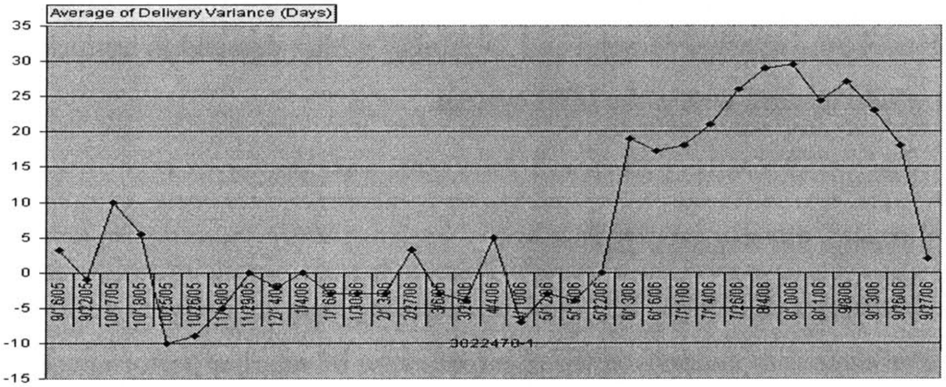


Figure 12: Receipt History of a Component Experiencing a Quality Excursion

Another major challenge with determining an accurate supplier delivery performance is the ability to assess whether late receipts are due to internal expediting procedures. As mentioned above, customers oftentimes place orders within lead-time. These unplanned orders, in turn, force buyers to place orders to their suppliers within the lead-time as they try to do whatever they can to meet customer needs. While this is the nature of the business, the metrics would indicate that the suppliers did not deliver parts on-time if orders for those parts were placed within lead-time.

There are also distinct challenges with supplier delivery that are unique to the aerospace industry. Because of the long lead-times associated with this industry and the high turnover in sourcing planners and buyers, often times, the person placing the order is not the same person receiving the order. Accordingly, it is difficult to pinpoint why the order was initially placed. For example, we would not be able to identity whether it was placed to mitigate an issue that occurred over a year and a half ago. Moreover, the combination of long lead-times and high attrition of planners and buyers makes it very difficult to hold planners and buyers accountable for potential inventory mismatch.

3.4 Results and Analysis

3.4.1 Baseline

The baseline for the 131-9 APU was determined by looking at the three-month average inventory levels and the three-month rolling service level performance. To obtain the inventory levels, the EPC categorizes inventory into three buckets: RAW, Work-In-Process (WIP), and Finished Goods Inventory (FGI). Table 2 below shows the percentage distribution for each category with respect to the overall inventory levels. Honeywell has an order policy of 5 Days of Supply (DOS) for A parts, which are 80% of the total parts cost, 20 DOS for B parts, which are 15% of the total parts cost, and 60 DOS for C parts, which are the remaining 5% of the parts cost. Honeywell does not have a safety stock strategy for the majority of the parts in their inventory. Therefore, with the long cycle times, the material in RAW is expected to be less than the material in WIP. However, that is not the case with the current performance. Table 2 indicates that 56% of the inventory resides in On Hand. Even if you calculate out the amount of cycle stock inventory based on the order policy, the resulting percentage should only be 11% of the total inventory. As a result, the On Hand value is 45% of what the planned inventory level should be. This 45% is, in effect, amounts to the unintentional safety stock that is needed to support the current service level performance. While most of the inventory is held On Hand, the FGI shown in Table 2 below is merely 2% of total inventory holding. This is due to Honeywell's policy of not holding any inventory at the line assembly level and the finished goods level. The 2% finished goods inventory derives from APUs sitting at the dock waiting to be shipped. It is important to acknowledge the low level of FGI because the easiest way to improve customer service level is to increase the FGI. However, this approach can be costly and with Honeywell's policy, the Model will have to come up with the best alternative solution.

	Receiving	On Hand	WIP $ On Floor	WIP On Hand	FGI	Total
Avg. Aug-Nov	1.3%	55%	37%	5.5%	2.0%	100%
Total	56%		42%		2%	

Table 2: Baseline Case- Percentage of total inventory holding

The service level performance for the 131-9 APU was measured at 78%. This includes serving both customers and AMS. Figure 13 shows the On-Time-to-Request Performance for the 131-9 product from July through October of 2006. There are three performance metrics used in the analysis of On-Time-to-Request Performance: Average On-Time to Schedule, Average On-Time to Schedule Plus Two, and Average On-Time to Request. Average On-Time to Schedule is the measurement of whether or not the engines were built against the master production schedule. Since production planners often shuffle the schedule to level load production, APUs are often built earlier than the customer's request date. The Average On-Time to Schedule Plus Two is designed to measure the production performance against Honeywell's schedule with a two day grace period because many customer contracts have a built-in grace period. The Average On-Time to Request is the measurement of performance against the request date. Oftentimes, the engines are built much earlier than the request date to help smooth the production schedule and also allow from material delay.

As indicated in Figure 13, Average On-Time to Schedule is at a low 15%, meaning that APUs are not built on schedule 85% of the time. In fact, on average, it takes three extra days for the remaining 85% of APUs to be completed. With an additional 2 day grace period under the Average On-Time to Schedule Plus Two metric, the performance improves significantly to approximately 50%. Fortunately, there is room in the build schedule such that even with these delays the Average On-Time to Request metric improves to 78%.

There are several implications to the results graphed in Figure 13. First, an APU is rarely built on schedule. Second, 35% of the APUs built is missing parts that are delivered 2 days late. Third, there is significant buffer room in the schedule to make up for the delay. In this case, 28% of the APUs ends up being on time to the customer even though it might have been late to the build schedule. Finally, this buffer in the schedule may have a rippling effect on the manufacturing floor, the suppliers and even the sourcing planners. When there is slack in the schedule, the need to deliver on-time performance becomes less critical. Moreover, each stakeholder knows that there is schedule built in for delays and thus can further exacerbate the situation. This in turn leads to high inventory, excessive overtime, and a lot of buy backs from its internal customers, the AMS. In fact, between September 2005 and September 2006, the total amount of buy backs between OEM and AMS was roughly $1 million dollars. This means AMS often plays the role of a safety stock warehouse and part of its inventory should be added to the baseline inventory levels in Table 2. While it is unclear whether AMS serves as more of an aid or a hindrance to the OEM, what is clear is that data captured in the Honeywell systems often appears much better than reality.

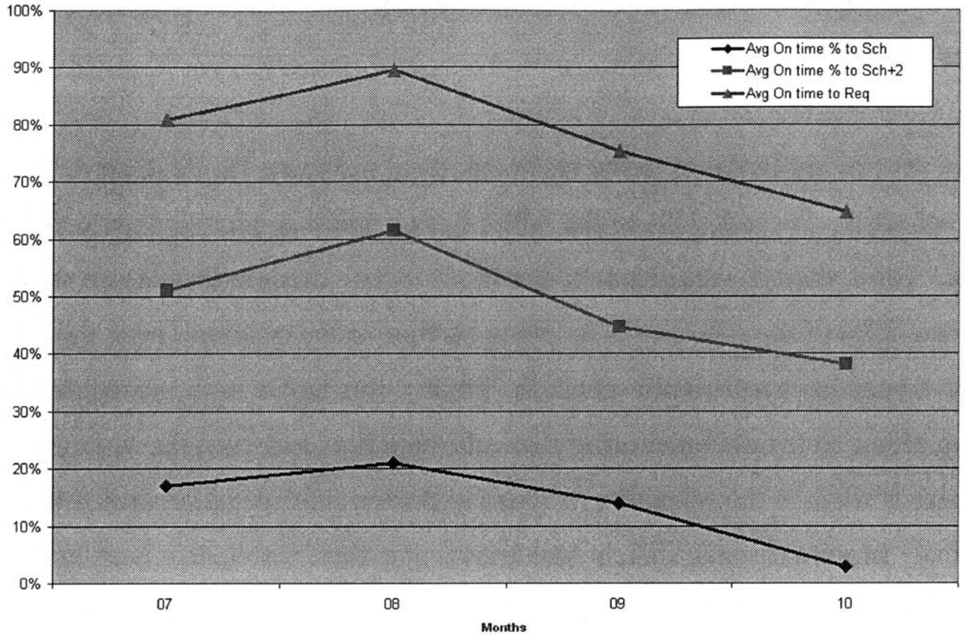


Figure 13: 131-9 On-Time-to-Request Performances in July to Oct 2006

3.4.2 Model Results

Table 3 and Figure 14 below show the results of the Model for the 131-9 product family. Compared with the breakdown set forth in Table 2, the Model provides further sub-categorization within each category. For example, within the Raw Material (RAW) On-Hand category, the Model suggests that 31% of the total inventory holding be held for safety stock, 11% of the total inventory holding be held for cycle stock and that 2% of the inventory likely be held in storage waiting to be consumed. This means 44% of the total inventory will be held at the RAW stage.

In the Model, inventory is clearly presented as cycle stock, pipeline stock or safety stock. Therefore, as improvements are made to reduce variability within the system, managers can use this breakdown to form a realistic target as to how much inventory savings to expect. Because percentages are used to disguise the true values of the inventory cost for confidentiality reasons, the denominators of the baseline and the Model results are not necessary the same. In fact, for the 131-9 Model, the total inventory recommendation for true values is actually 13% higher than current performance values presented in this example. This is because the targeted service level for the Model is set at 95% rather than comparing with the baseline at 78%. Therefore, inventory optimization via a 13% increase in inventory will help improve service level by 17% from 78% to 95%. With this result, the 41% safety stock recommendation can be repopulated back into the material flow diagram from Figure 10. This will enable managers to see not only how much inventory is needed to support a 95% service level strategy, but also where in the supply chain this inventory is located. Figure 15 shows the updated material flow diagram. Although it may be difficult to see through this diagram, the model's recommendation to place safety stock at strategic locations, based on service time requirement, contradicts the conventional approach of placing safety stock at each stage in the supply chain. This is in line with Willems research, that the decision of where to place safety stock in the supply chain is of significant strategic importance since it dictates the major decoupling points in the supply chain and identifies where the major constrains reside[xxvi].

	RAW	WIP $	FGI $	Total $
Safety Stock	31%	10%	0%	41%
Cycle Stock	11%	0%	0%	11%
Pipeline Stock	0%	36%	0%	36%
Early Arrival Stock	2%	1%	9%	13%
Total	44%	47%	9%	100%

Table 3: 131-9 Model Result for Inventory Buckets

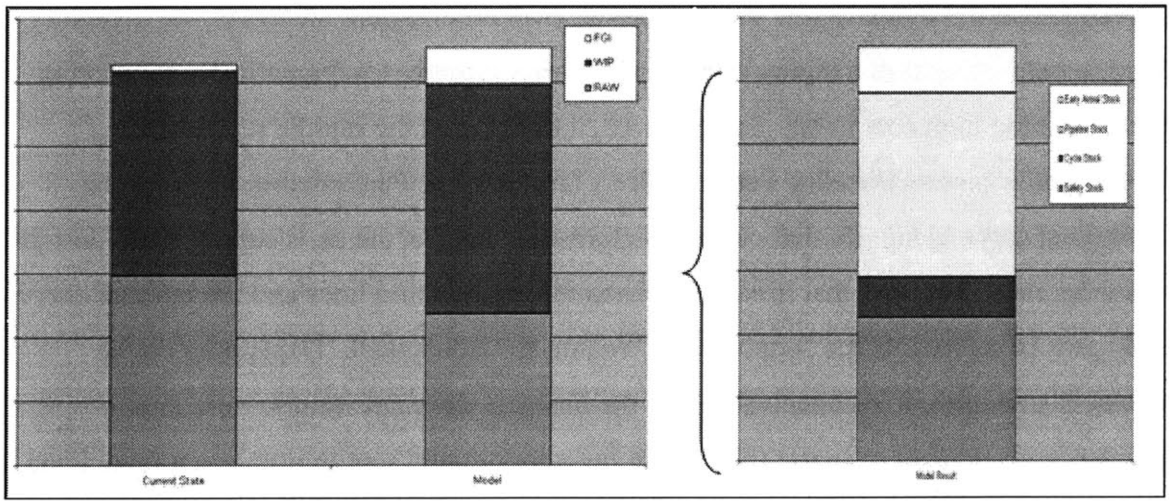


Figure 14: 131-9 Inventory Breakdown

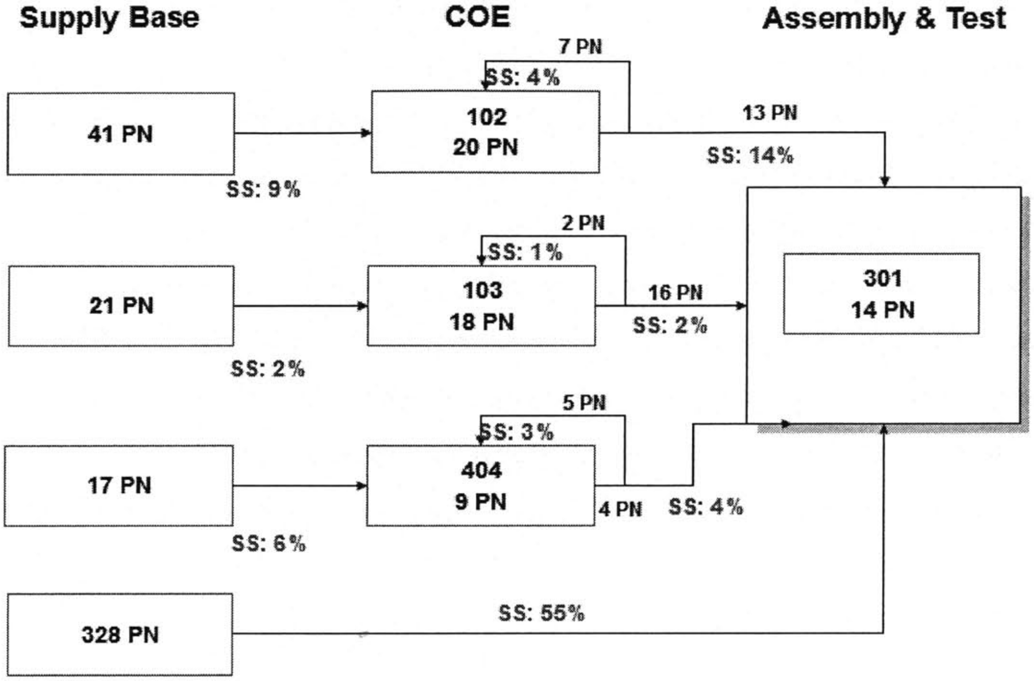


Figure 15: Material Flow Diagram for 131-9 APU with Safety Stock Targets

With the information at hand, the next question to answer is how much inventory is needed to support a 78% customer service level? In other words, how effective is the current system? The Model was re-run with the 78% service level target and the result indicates that the system is currently 19% higher than necessary in inventory. To put this into pictorial form, Figure 16 illustrates the relationship between Total Inventory Investment and Service Level. As the service level requirement increases, the inventory investment increases at a higher rate because the cost increases dramatically for serving the remaining high cost items. In Figure 16, the square in the middle represents Honeywell's current Baseline Performance. The Baseline Performance is above the optimized curve to signify that current performance against the as-is supply chain design is suboptimal. The area that is captured between the two thin lines and the optimal curve in Figure 16 represents the "opportunity" region for Honeywell. Depending on the business strategies, it is conceivable that the business does not want to raise any inventory investment or to use the current inventory investment to improve service level. Accordingly, the resulting service level would be at 90% rather than 95%. However, this would still be an improvement from 78%.

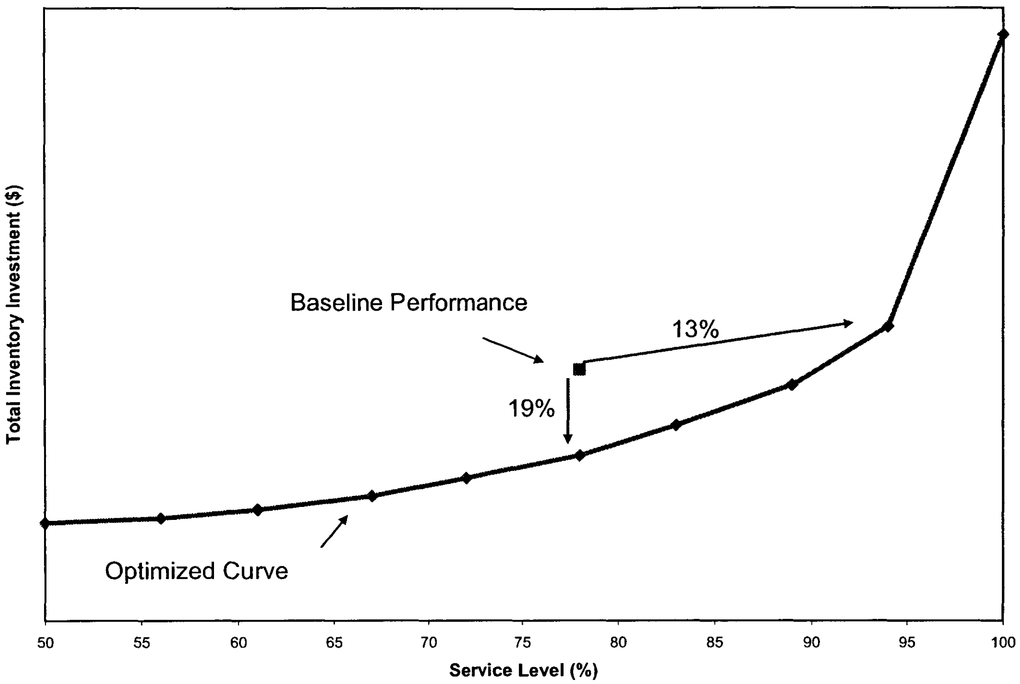


Figure 16: 131-9 Curve- Inventory vs. Service Level

The Optimized Curve in Figure 16 represents the optimal performance that one can achieve under the as-is supply chain. This means, taking into account the variability of supply and demand as well as incorporating order policy and manufacturing design, the curve is the best performance one can achieve. Therefore, if the baseline performance is not on this optimized curve, it means that there are inefficiencies within the system and performance is not meeting the potential of the design. An example of this is when buyers deviate from the order policy. While the order policy may require buyers to have five days worth of A parts on hand at all times, buyers can choose to order more than five days worth to build their safety stock. Since the buyers do not have a recommended safety stock level, they will often order more than they really need. If this happens for all parts within the inventory planning system, the resulting inventory level would be out of control. Therefore, the first step of inventory reduction is to right-size the current design. Right-sizing is the process of calculating how much inventory is needed and where in the supply chain it should be held to support the customer service level. Once it is clear as to what the targets are, the next step is to eliminate inefficiencies by adhering to the order policies, executing the manufacturing lead-times and delivering on commitments. This is one method to reduce inventory while improving customer service.

Alternatively, management can evaluate the supply chain design to determine which lever has the highest sensitivity to inventory performance. This can be done by running sensitivity analyses in *PowerChain* to see which input parameters have the highest effect on inventory. Before doing so, a Model was ran to assess the impact of restricting inventory holding at line assemblies and at the finished goods inventory node. The resulting curve is shown in Figure 17.

In Figure 19, the lower curve represents the Optimized Curve under the new supply chain design. As one can see, the potential for inventory improvement is higher at lower service levels and less at higher service levels. This makes sense because the change in the supply chain design is based on holding strategy; therefore, the variability in supply and demand did not change and the required safety stock remains comparable.

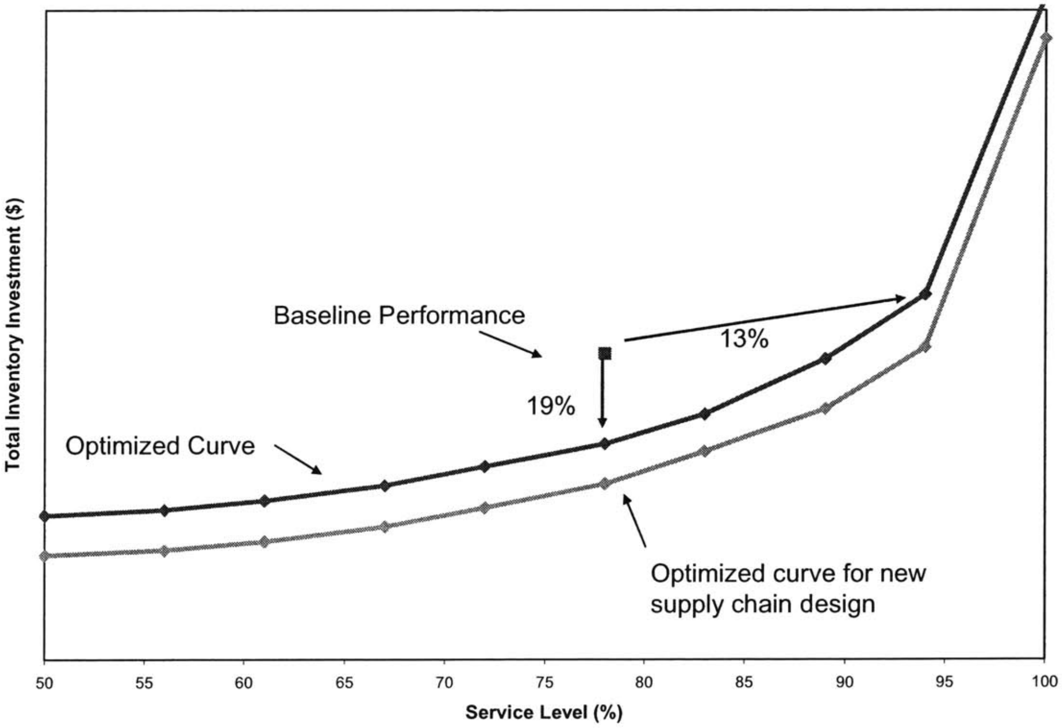


Figure 17: 131-9 Curve- Inventory vs. Service Level with New Supply Chain Design

3.5 Inventory Right-Sizing

As mentioned in Section 3.4, the first step to inventory optimization is to right-size your inventory. Figure 16 demonstrates the high-level potential of right-sizing, but actually implementing this solution requires looking at it m a detailed level. Since the Model was designed around part numbers, the best way to determine how to right-size is at the parts level. Figure 18 shows the Over and Under Analysis for the 131-9 Model.

The Over and Under Analysis is a comparison of the inventory investment needed for each part number between the current On-Hand Balance (OHB) (in blue) and the Optimized Results (in magenta). Any part, in which the diamond dot is above the dotted curve, represents a part that is overstocked. Conversely, any part that has the diamond dot below the dotted curve represents a part that is under stocked and that the majority of production stoppage may be due to these parts. Note that in Figure 18 some parts may be at the low end of the replenishment cycle and will be lower than the average value provided by the Model. Nevertheless, this comparison will provide key insight as to which parts should be the primary focus for improvement from a cost perspective.

Specifically, for the 131-9 Model, 140 part numbers were found to be under stocked while the remaining 328 part numbers were over stocked. Figure 18, however, shows a lot of part numbers that are on the tail end of the curve. Therefore, even though they may be overstocked, they would amount to very little from a cost perspective. Strategically, these are parts that shouldn't be focused on. On the other hand, for parts that are under stocked, it is critical to focus on the low cost items. These low cost items can be quickly implemented and the service level can increase dramatically without much cost. Another method of comparison is necessary to help prioritize where to start right-sizing at the parts level.

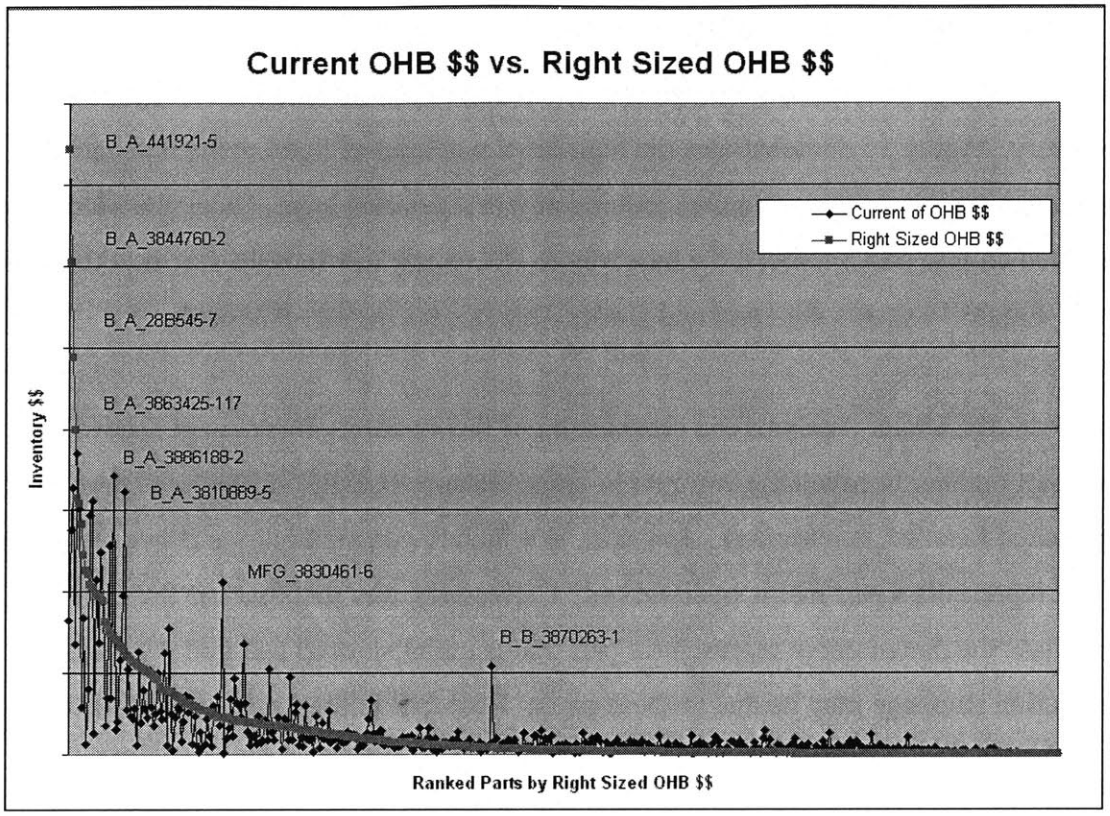


Figure 18: 131-9 Over and Under Analysis

3.5.1 Safety Stock Matrix

Since managers often have to balance between the conflicting metrics of inventory level and service level, a safety stock matrix was created to compare these metrics at the parts level. Figure 19 sets forth the matrix for the 131-9 Model. The x-axis measures/charts the service level impact of a particular part that is derived from measuring the number of days in safety stock recommended by the Model. The y-axis measures/charts the inventory investment impact of a particular part that is calculated from the safety stock investment recommended by the Model. By plotting each part number against these dimensions, it becomes very clear which parts have the highest service level impact, the highest variability, and the highest cost impact. Four major categories emerge from this analysis: 1) Parts that have high service level impact but can be fixed with low inventory investment; 2) Parts that have high service level impact but can be fixed with high inventory investment; 3) Parts that are high cost but have little service level impact; and 4) Parts that are low cost and have little service level impact.

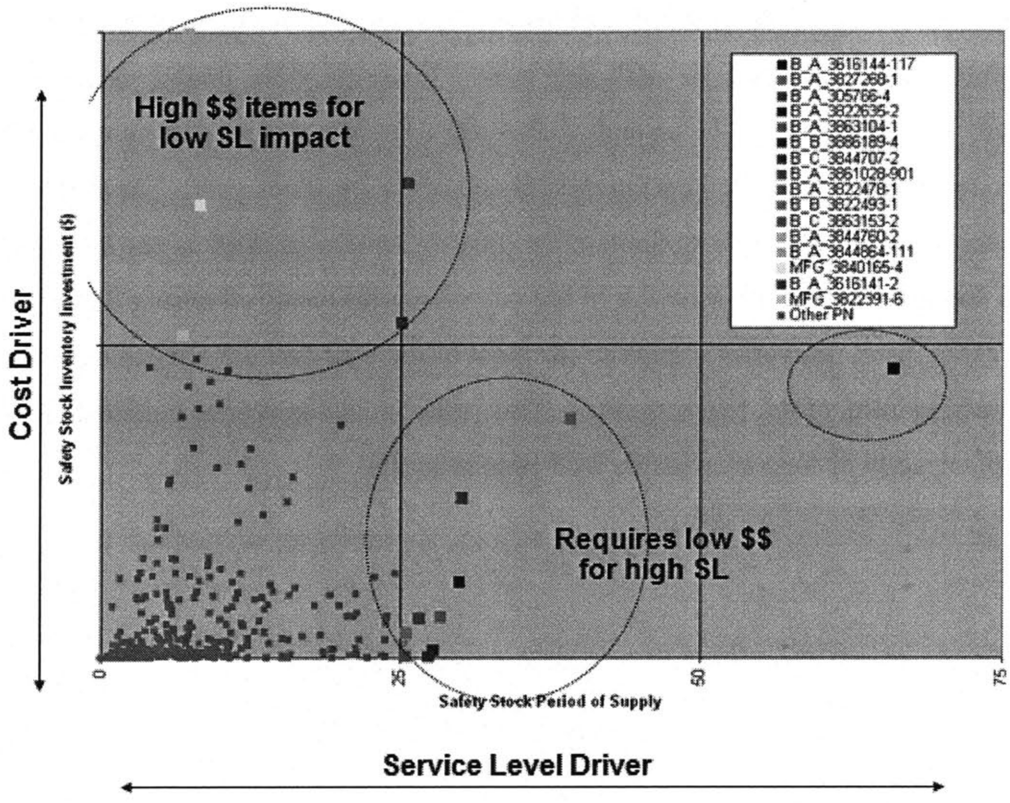


Figure 19: Safety Stock Matrix for 131-9

As shown in Figure 19, there is one part number that exhibits both high-cost and high service level impact. Nine part numbers appear to have medium service level impact and are relatively low inventory cost. Six part numbers are high in inventory cost but may not have a high level of impact and the remaining parts at the lower left quadrant appear to be both lower cost and service level impact. The categorization of these parts is arbitrary and as improvements are made to the high-runners, a new set of high-cost, high-impact parts will emerge and further analysis will be required to assess their root causes.

3.5.2 Performing Deep Dives on the Safety Stock Matrix Outliers

From the results shown in Figure 19, an additional "deep-dive" step was taken to analyze the data before implementing the recommended solution. The purpose of this deep dive was to understand the root cause of the outliers circled in Figure 19 and determine if it was a one-time event. Since supply variability is a backward looking process, it is important to understand the root causes of variability so a safety stock target is not implemented for a problem that has been fixed. Specifically, for the 131-9 Model, 13 part numbers were analyzed. In analyzing these 13 part numbers, three consistent themes emerged. First, there seems be an end-of-the-year effect on several part numbers when the late deliveries all occurred during the tail end of the previous year. The delivery profile for a particular part from September 2005 to September 2006 is shown in Figure 20. As shown in Figure 20, the peak of the late deliveries occurred during September 2005. From there, deliveries improved for most of the year and then began to spike back up in the beginning of the fourth quarter. This spike in late deliveries could be due to issues of capacity or increased inside lead-time requests.

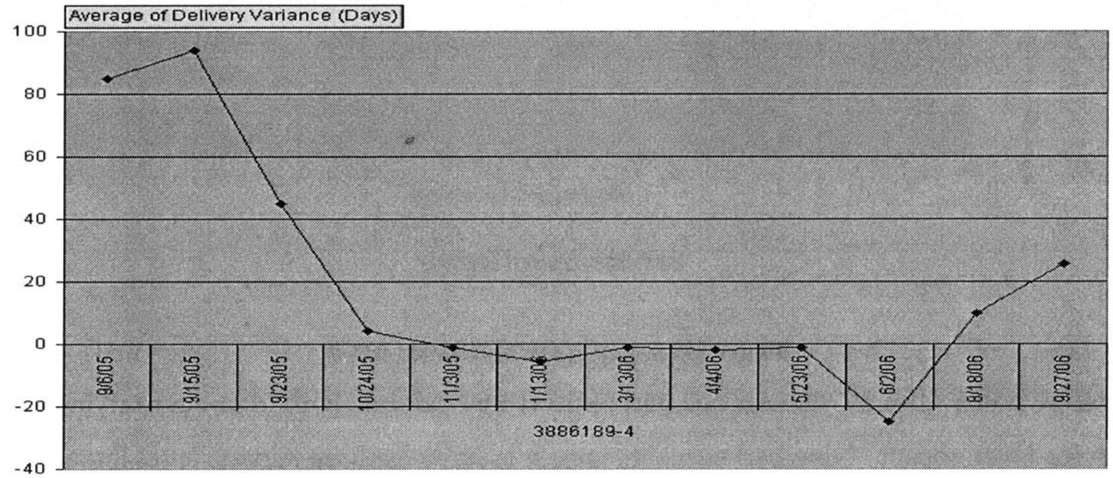


Figure 20: Receipt Profile to Capture EOY Effects

The second theme is that many part numbers had one-time quality excursions during the beginning of the year as shown in Figure 21. Discussions with some buyers indicated that a possible explanation is that suppliers focus heavily on meeting the end-of-the-year demand and, as a result, quality often suffers. Unfortunately, it is also not until the beginning of the following year that the issue is understood. As a result, even if suppliers are able to meet the end of the year demand, there are consequences, which result in late deliveries in the later months.

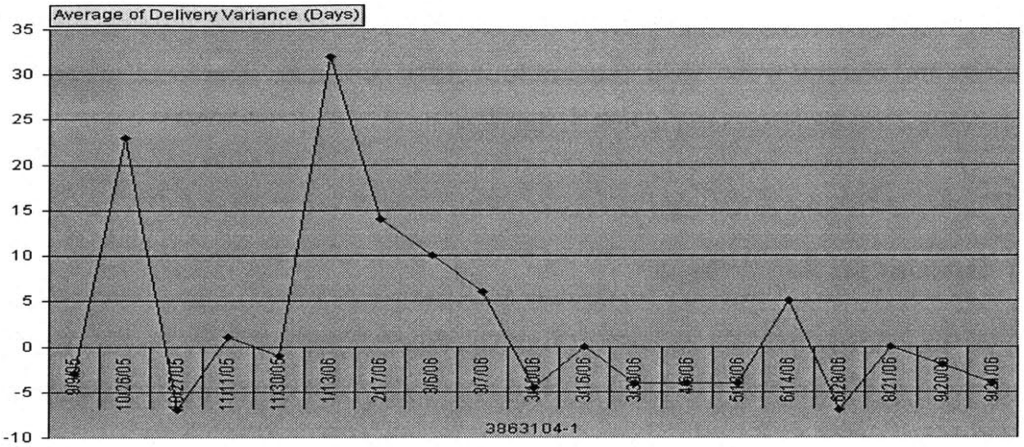


Figure 21: Delivery Profile for One-Time Excursions

The last theme is that the majority of the 13 parts had AfterMarket Service (AMS) demand. An examination of the demand patterns in Figure 22, indicates that AMS places its demand on a monthly basis. While demand for most parts is, on average, 15 units from the OEM, AMS demand increases that amount by three to five times at the end of each month. Moreover, because of the increase in week-to-week variability, extra safety stock is recommended. When AMS planners were asked about the reasons behind monthly demand, they stated that there is no particular reason for placing monthly demand at the end of the month except that it was the default setting in the planning software.

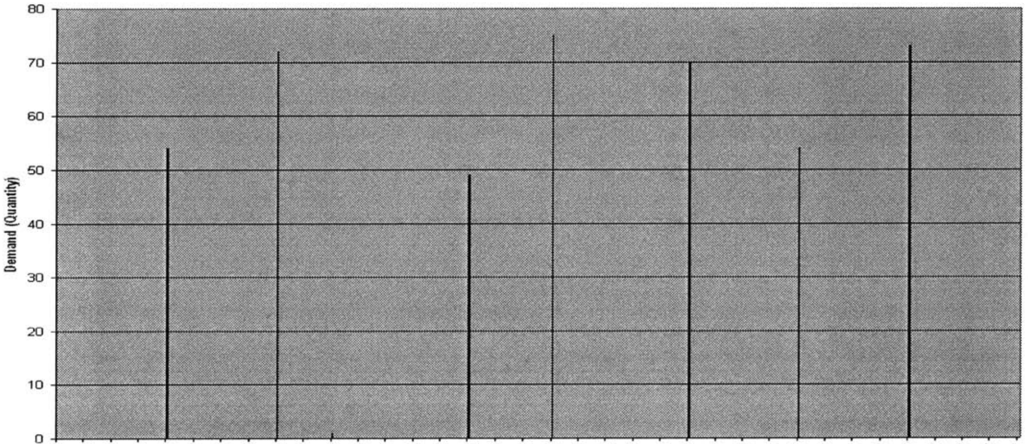


Figure 22: AMS Demand Profile for 131-9 Parts

After the deep dives were completed, the Model was rerun removing the one-time excursions and changing the AMS demand to weekly demands. The resulting safety stock recommendations showed a 20% reduction.

3.5.3 Reasons for Safety Stock

Now that the Model has been updated with the changes mentioned above, the next step in the process is to understand the drivers behind the safety stock recommendations and to look at it from a different angle to come to general conclusions.

Figure 23 provides a breakdown of safety stock recommendations based on causes and supply or demand variability. The lower sub-bars within each category represent the parts purchased outside of Honeywell. The upper sub-bars represent the parts that are made internally (Make). Based on Figure 23, supply variability shows a greater impact than demand variability. From the purchased part (Buy) perspective, this could be due to delivery issues or poor yield. In contrast, from a make part perspective, this could mean variable cycle time and poor yield as well.

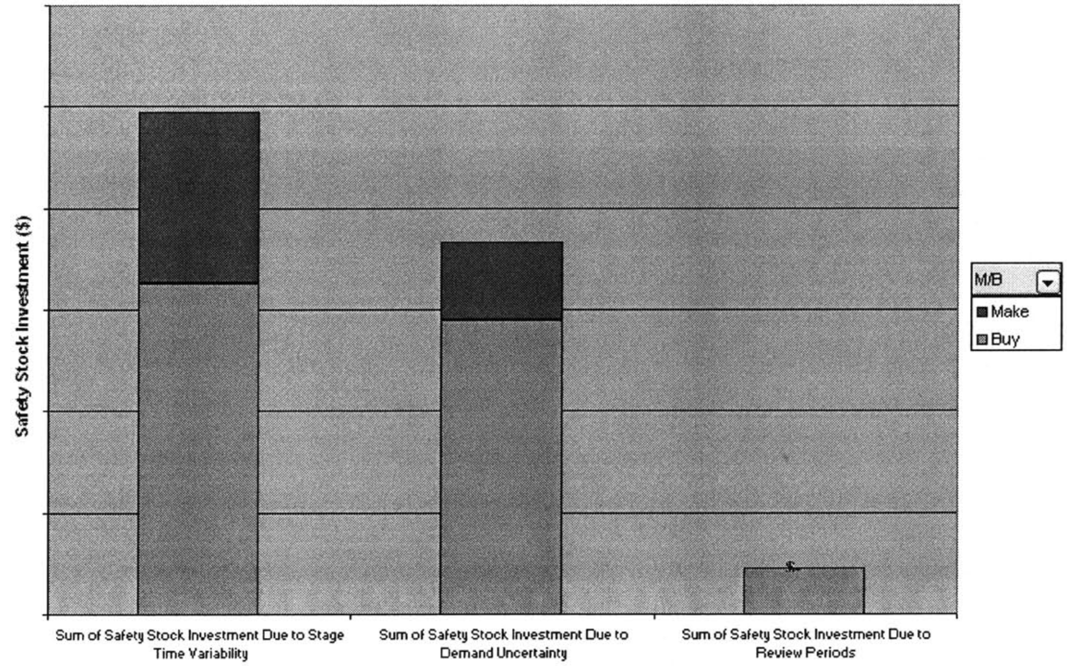


Figure 23: 131-9: Causes for Safety Stock

3.5.4 Safety Stock due to Suppliers

Taking this further, the supply variability bar can be broken down further into individual suppliers to see if there is a trend in supplier performance. Figure 24 shows the suppliers ranked against the safety stock investment levels. What is interesting about this graph is that the 80/20 rule applies: 80% of the safety stock investment is accounted for by 20% of the suppliers. These 20% suppliers are further analyzed in Figure 25. The top two suppliers needing safety stocks in Figure 25 are the two internal COEs, 102 and 404. Because there are two sources of variability-- supplier delivery and manufacturing cycle time, and because these two sites supply the majority of their parts to Final Assembly, from a cumulative spend standpoint, they account for the highest amount. Therefore on a per part basis, parts from COE 102 and 404 are actually not high safety stock investment drivers, but rather parts Meyer Tool as shown in Figure 26 are the high safety stock investment drivers.

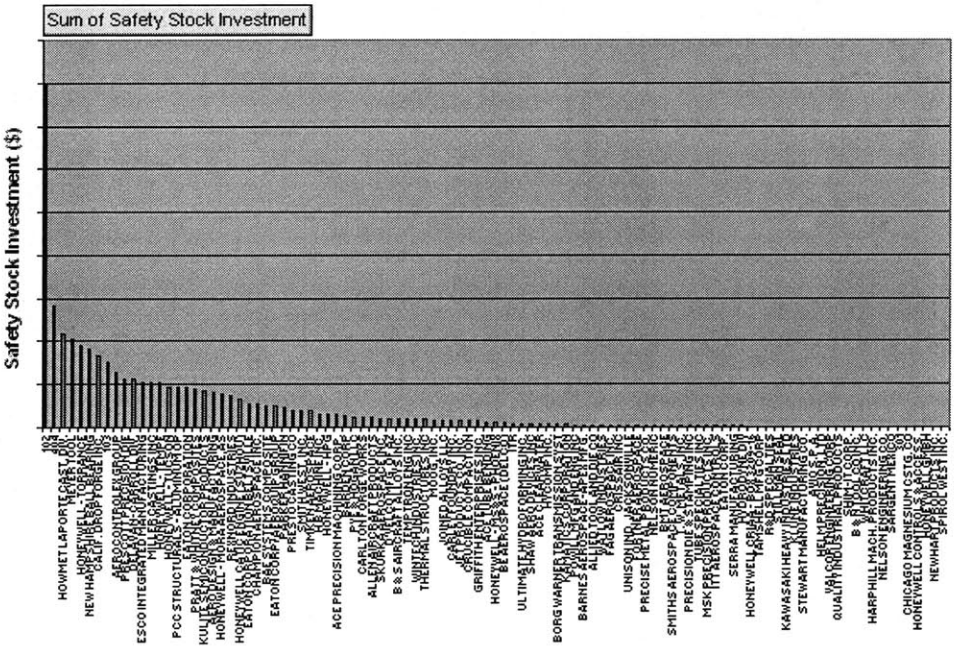


Figure 24: 131-9 Supplier Performance

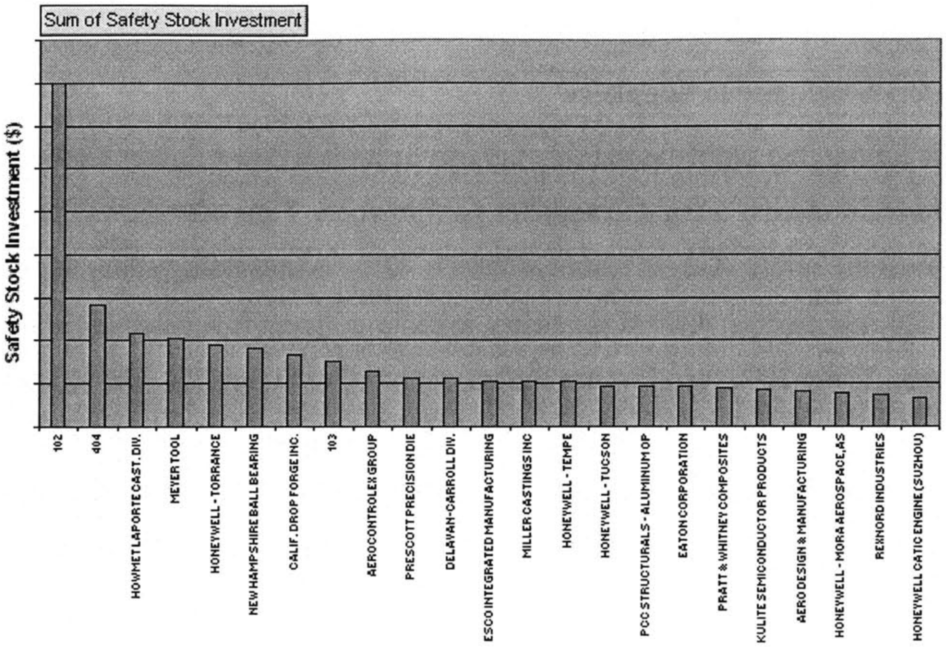


Figure 25: Top Suppliers (80% of Safety Stock Investment)

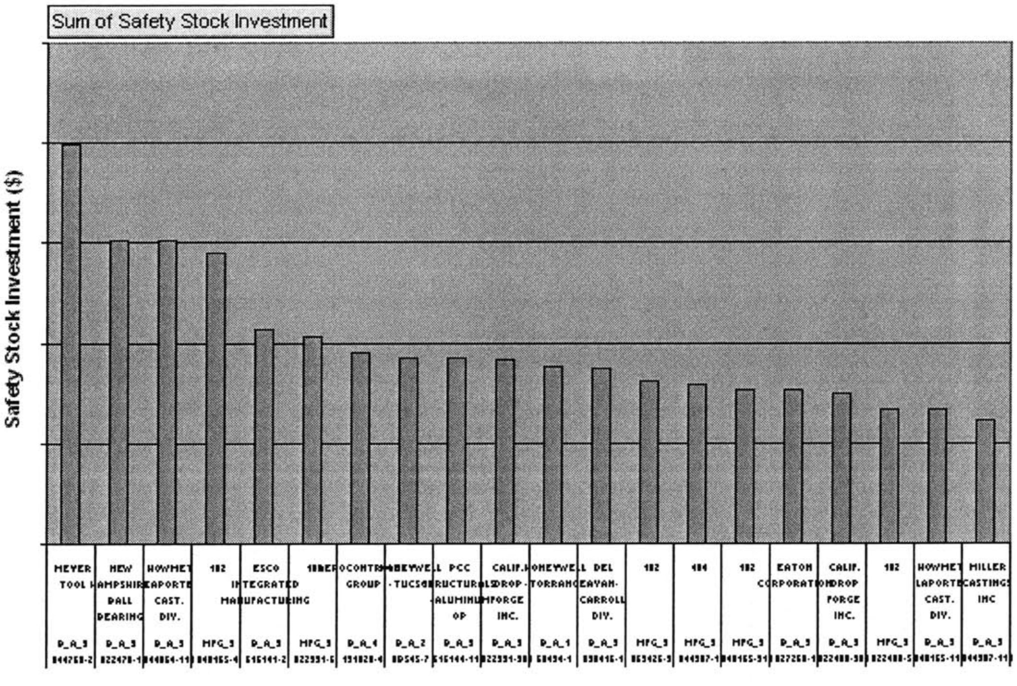


Figure 26: Safety Stock Investment Ranked by Part Number

In Figure 26, it appears that there are only few repeat suppliers. In fact, if the safety stock investment is sorted by suppliers, suppliers are not consistently low-ranking across all the parts they supply, but rather, only a small subset (see Figure 27). Based on this information, it is hard to reduce inventory from a supplier perspective and one will have to look at individual suppliers and individually evaluate the root causes of their poor delivery performance.

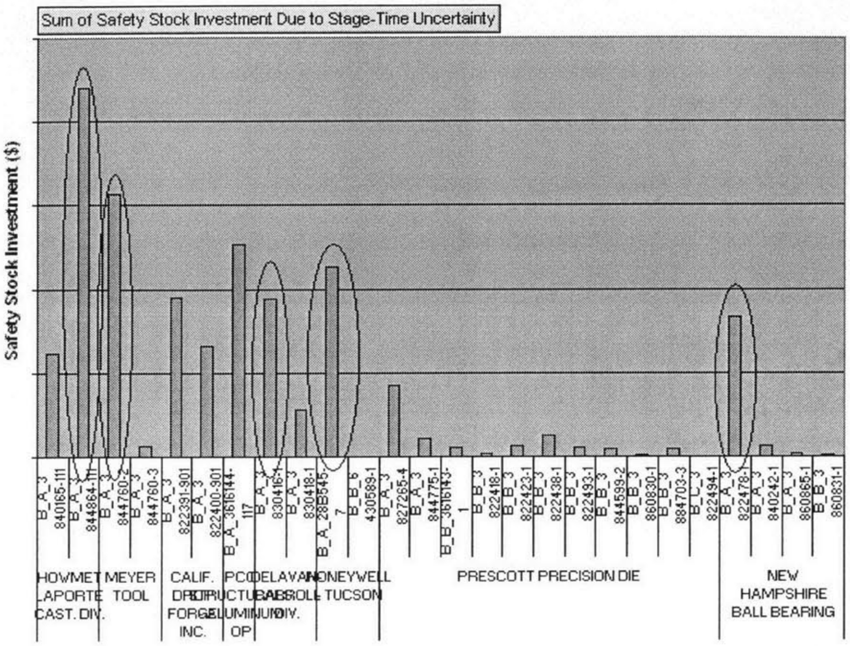


Figure 27: Safety Stock Investment by Suppliers

3.5.5 Safety Stock by Service Level Impact

The Safety Stock Matrix shown in Figure 19 provides a high level view of the part numbers with the highest service level impact. Most of these parts can be resolved with little investment. When these parts are further analyzed, it appears that internal manufacturing sites supply most of these parts. In fact, eight out of the top twenty parts come from Honeywell's Product Group (HPG), supplier of the nuts and screws (Figure 28).

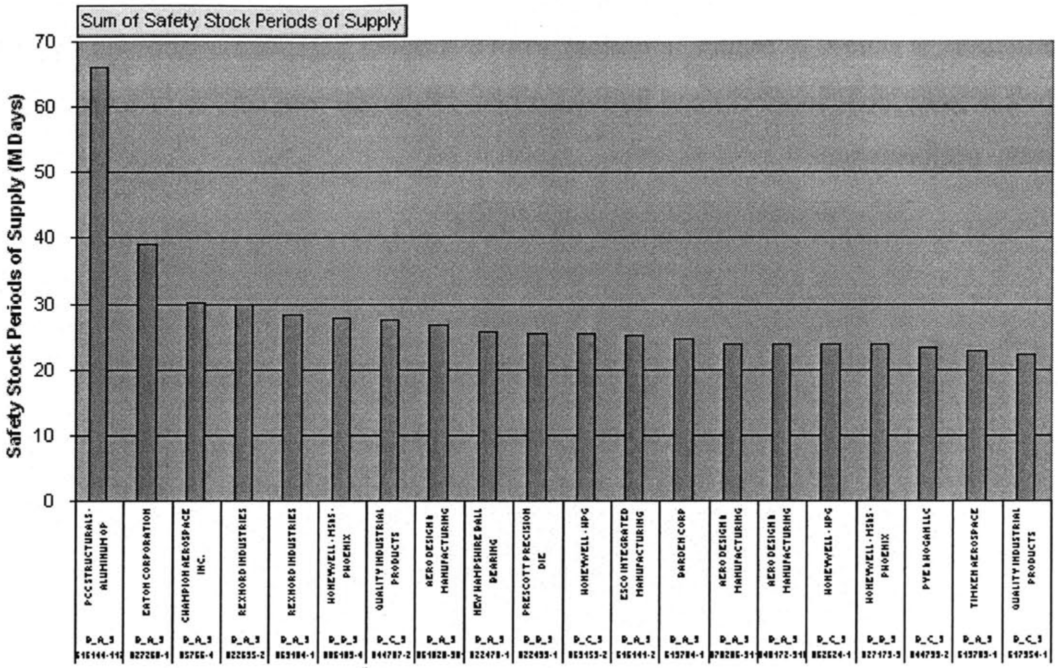


Figure 28: Safety Stock Periods of Supply by Suppliers

3.6 Challenges with Implementation

Although the pilot is currently being implemented and results are not yet available for discussion in this thesis, there are still many challenges in formulating the implementation strategy. First, the EPC was using a legacy planning system, MacPac, and will not be upgrading to SAP for another year and a half. According to the sourcing planners, the MacPac system was developed in the 1970's and, until recently, there has not been a major upgrade with the SAP implementation in other product centers within Honeywell. While the MacPac system does allow for safety stock in the planning process, it does not work well with Honeywell's Firm Purchase Order Timefence (FPOT) system. FPOT is the contractual agreement Honeywell has with its suppliers whereby firm POs are not placed until 30 days of the delivery date even though these parts may have been forecasted two years ago. With MacPac, unless the order is driven from actual demand, the safety stock targets get updated on a weekly basis and refresh back to the lead-time of the part. Therefore, if a part has a lead-time of 100 days, after a week, instead of expecting the parts in 93 days, the system will refresh, recalculate the lead-time and update the delivery date 100 days out. To work around this constraint, Honeywell's management considered creating dummy demand to trick MacPac. The problem with utilizing dummy demand is if there is a capacity constraint, there is a possibility that a dummy demand will get prioritized over the actual demand and that the actual demand will have to be pushed out. This would essentially defeat the purpose of the safety stock.

Another challenge with implementation of the Model is capacity and resource constraints. Currently, the COE facilities are already under a lot of pressure to meet daily outputs. It will take a long time for them to have the capacity to build up safety stock. However, this is not just an internal problem because suppliers are also facing similar issues. Consequently, it may be unrealistic to expect immediate improvements in either inventory or service level. Nevertheless, inventory optimization provides a good view of the potential savings. It also helps to identify what stage of the supply chain requires the most management focus.

3.7 Sensitivity Analysis

Although there was limited focus on evaluating the sensitivity of the Model during my internship, initial results do highlight some interesting observations. Specifically, four parameters were evaluated: 1) Average Make Part Cycle Time, 2) Cycle Time Variability, 3) Demand Variability, and 4) Purchase Part Lead Time as shown in Figure 29 to Figure 32. The figures show the change in inventory investment as a percentage change in each of the interested parameters. The baseline is measured at 100% and the incremental change in percentage is set at 10%. Therefore, it is clear how much extra inventory investment is necessary to support a 10% increase in cycle time.

Even though actual numbers are not provided, the shape of the curves is still quite revealing. For instance, in the Sensitivity Analysis on Make Part Cycle Time below, the slopes of the two lines are different; suggesting that the cost for a cycle time increase is much higher than the savings in cycle time reduction. Thus, it is more important for managers to make sure the cycle time is maintained at current performance rather than to expend extra effort to determine how to improve the process through reducing cycle time.

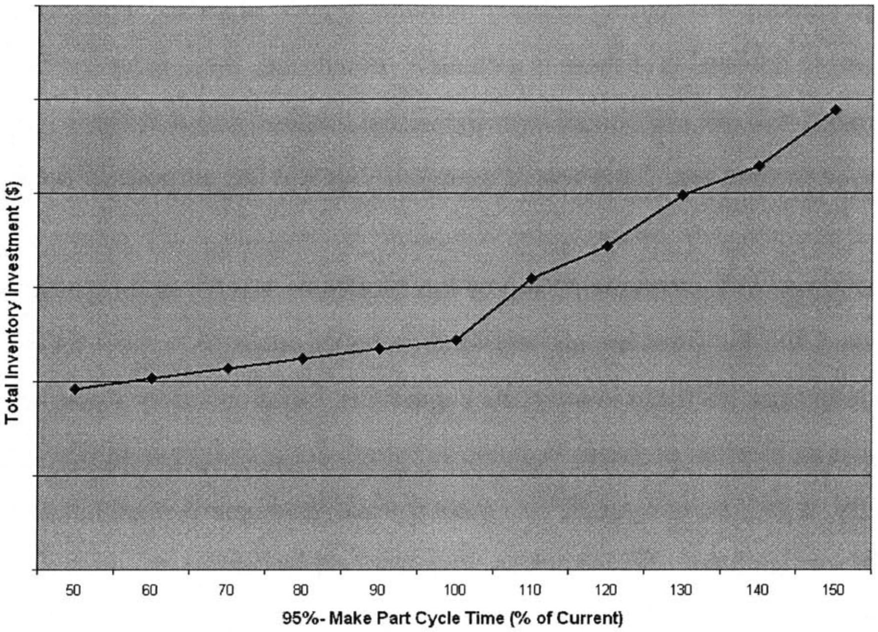


Figure 29: Sensitivity Analysis on Make Part Cycle Time

On the other hand, Make Part Cycle Time Variability shows only one line with one slope. This is due to a variation within the system that directly links to the safety stock calculation. As a result, reduction in variability would have the same impact as an increase in variability of the same amount.

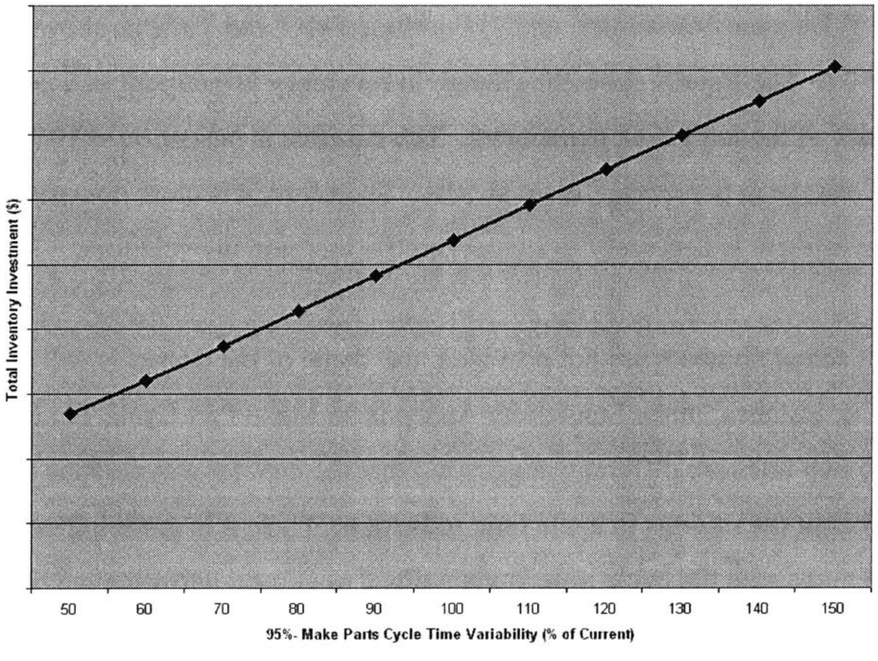


Figure 30: Sensitivity Analysis on Make Part Cycle Time Variability

In the AMS Demand Variability sensitivity analysis in Figure 31, the slope is the highest compared to lines in the other analyses. This reconfirms the discussion from above in which a reduction in variability from monthly to weekly orders can lead to tremendous inventory savings.

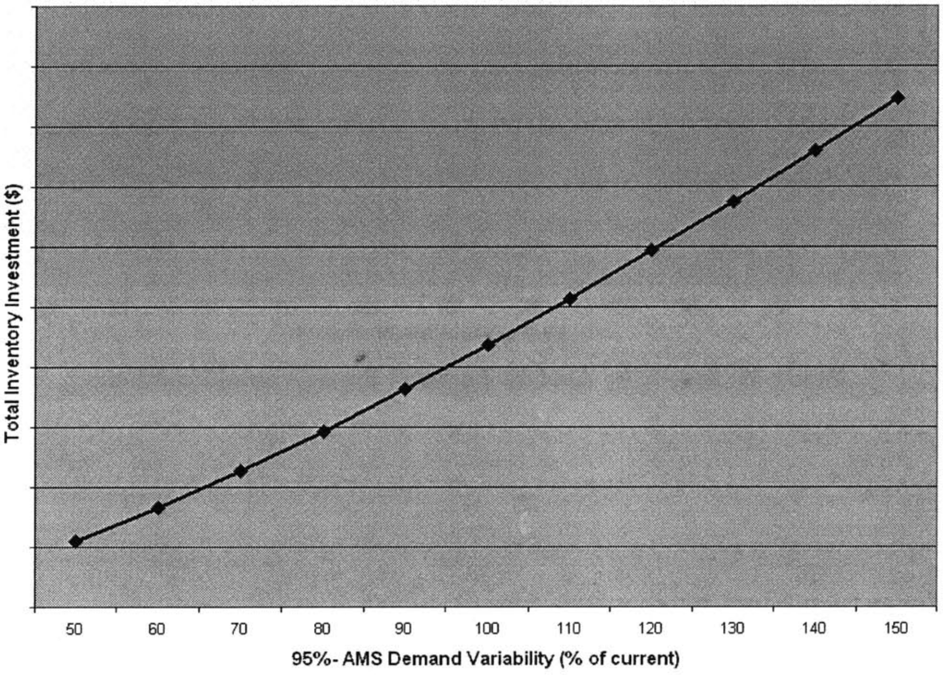


Figure 31: Sensitivity Analysis AMS Demand Variability

Last, in the Purchase Part Lead-Time Sensitivity analysis presented in Figure 32, the slope of the graph is increasing, but at a decreasing rate. This suggests that at a certain critical lead-time, the inventory investment flattens out and increased inventory will not improve service level. In other words, it no longer becomes cost effective to have more safety stock in the system. Since it is a balancing act between inventory cost and service level, at this point in time, the cost driver becomes the superseding objective over the service level driver.

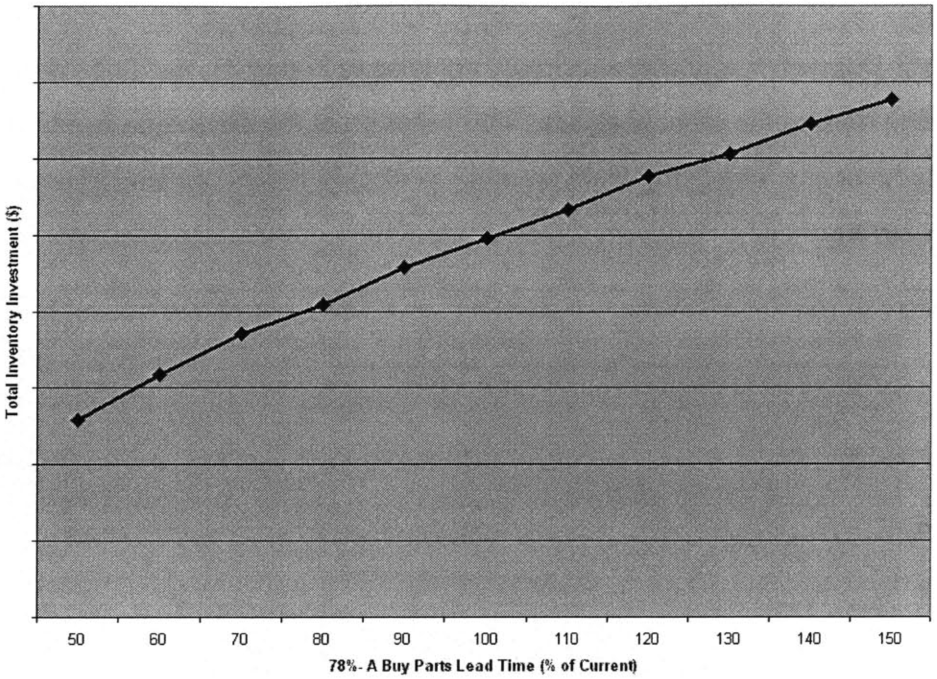
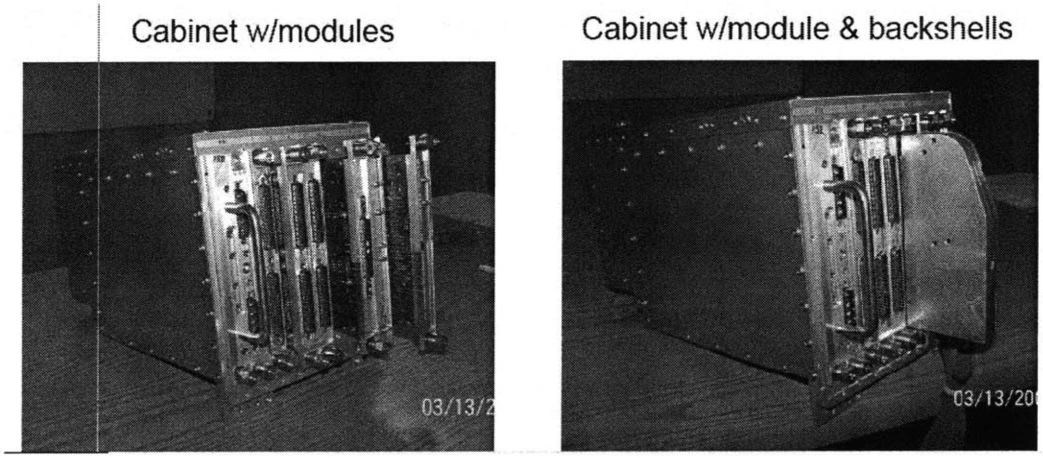


Figure 32: Sensitivity Analysis Purchase Parts (A only) Lead Time

4 Avionics Product Center (APC):

This chapter discusses a second pilot performed in Honeywell's Avionics Product Center (APC). Avionics is the application of electronics to aviation. In essence, it comprises all electronic systems designed for use on an aircraft, including communications, navigation and the display and management of multiple systems. At Honeywell, the APC makes products ranging from displays and cabinets to platform and Radio Frequency sensors. For the second pilot, the platform Modular Avionics Unit (MAU) was chosen, see Figure 33.


Cabinet w/modules

Cabinet w/module & backshells

Figure 33: The MAU Units

4.1 Inventory Optimization

The intent for piloting another model in a different product center was to understand how transferable the optimization methods were from the ones developed with the 131-9 Model and how effective it would be to optimize a supply chain that is less complex than the engine products. MAU was chosen specifically for its simplicity because it had 3 layers in the BOM with only 218 parts and only 13 of those parts have AMS demand. Furthermore, the APC is the most up to date on its data collection. Unlike other product centers, the APC has embraced the corporate database system, webPlan, and have many in-house experts to analyze and process massive amounts of data into usable information. This is another benefit of piloting in the APC. With the data readily available, it will be much easier to validate the results. Lastly, THE APC does not have the same legacy software system issue that EPC has because it is using SAP versus MacPac.

The remainder of this thesis will analyze the results gathered from the second pilot and set forth similarities and differences between this model and the 131-9 model.

4.2 MAU Model

Figure 34 shows the model for the MAU product line. Unlike the scenario with the 131-9 Model in which there were only two end-units, MAU has 45 end-units in this family. Each end-unit differs from the next end-unit only by a few parts. Also, the MAU product has been performing at a 90% customer service level. Therefore, it will be more difficult to squeeze the supply chain to achieve that remaining 5% target. This is because MAU is at the right side of the service level cost curve where the cost incurred to service the last 5% can be massive.

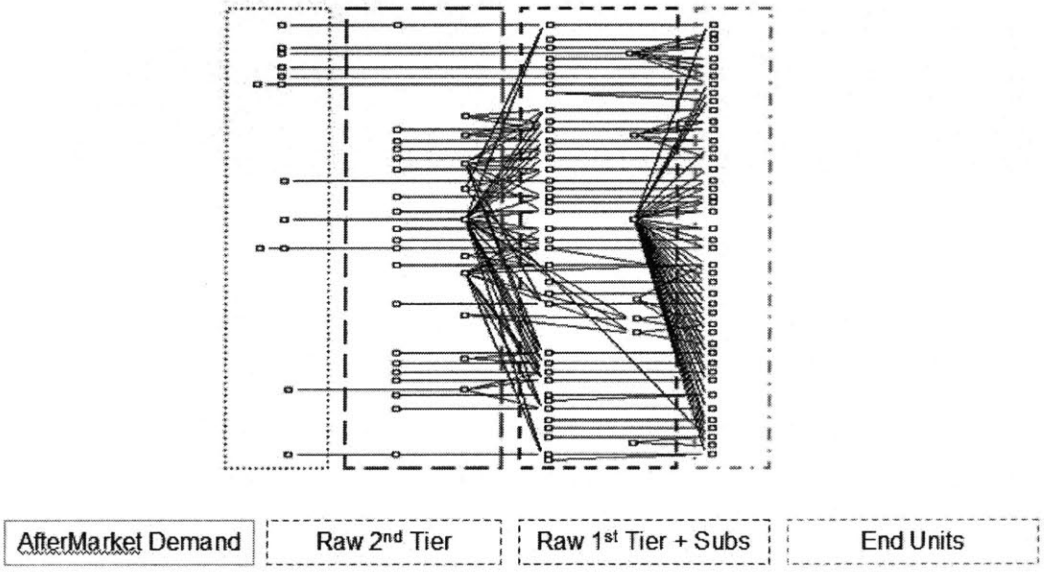


Figure 34: MAU Model

4.2.1 MAU Results and Analysis

Table 4shows the baseline for MAU. As demonstrated by Table 4, the majority of the inventory is either in WIP, Final Test (Final) or at Rework. This is because MAU has very poor yield. The average yield of the 45 end-units is 76%. Fortunately, the lead-time necessary to build a MAU is less than the purchase order lead-time, so there is significant buffer room within the schedule for rework to still ship the product on time.

	In House	On Hand	WIP	Final	Rework	FGI	Total
September 2007	0.5%	16%	36%	33%	0.5%	13%	100%
Total	16.5%		79.5			13%	100%

Table 4: MAU Baseline

Table 5 shows the optimized results from the *PowerChain* software for MAU. Unlike the 131-9 Model, the entire finished goods inventory and some of the work-in-process is pushed back into the raw materials' bucket. Because of the short lead-time required to build, it makes sense for the model to recommend holding zero finished goods on hand and holding more raw materials further back upstream when the cost is less. This result again supports Willems research that there are decoupling points within the supply chain where strategic inventories are all that are necessary to satisfy customer demand subject to a service constraint. Going through the same procedure of understanding the root cause, the breakdown for safety stock is shown on Figure 35. Since this product line has a very predictable demand, the safety stock investment due to demand uncertainty is relatively low. The safety stock investment due to the review period is calculated by looking at the timing of interaction between the A, B, and C parts. This value can be used to determine whether the 5 DOS for A parts, 20 DOS for B parts, and 40 DOS for C parts is the optimal order policy. Unfortunately, due to time constraints of the pilot, this analysis was not investigated further.

	RAW $	WIP $	FGI $	Total $
Safety Stock	30%			30%
Cycle Stock	7%			7%
Pipeline Stock		63%		63%
Total	37%	63%	0%	100%

Table 5: MAU Optimization Results

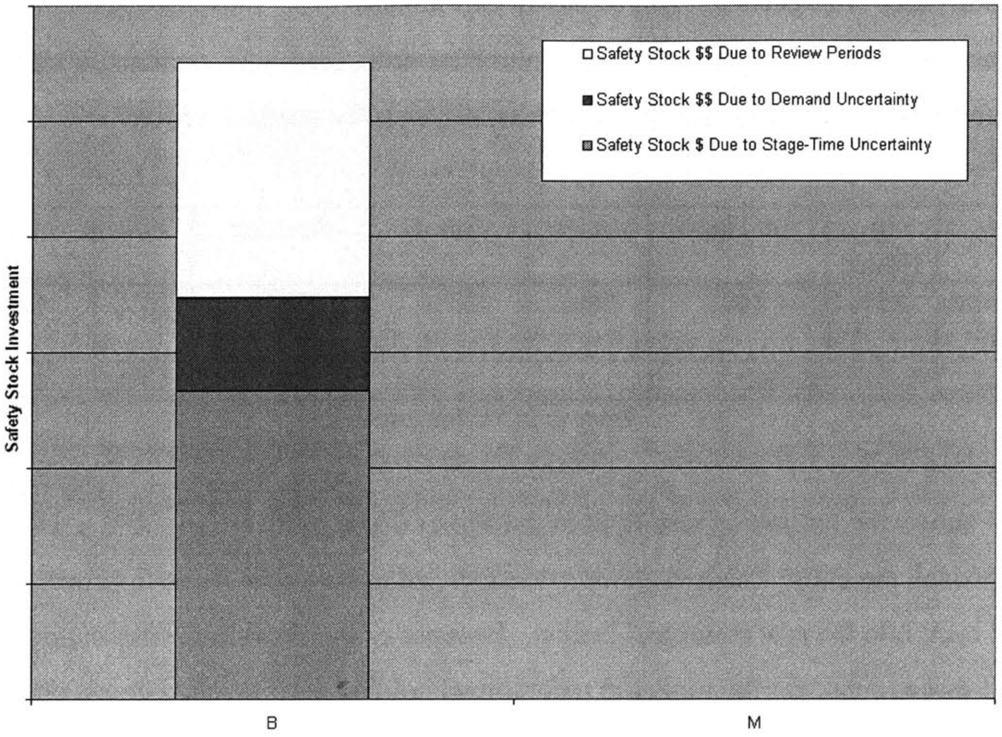


Figure 35: MAU Safety Stock BreakDown

From Figure 35, the largest contributor to safety stock investment is supply lead-time. Using the same approach as the 131-9 Model, the safety stock investment was broken down by supplier and by the impact to service level (Figure 36 and Figure 37). Interestingly, unlike the 131-9 model, which did not exhibit a supplier trend, here there is a correlation between high inventory investment and specific suppliers. In this product line, Celestica is the primary inventory driver. This is not unusual due to the fact that Celestica provides Circuit Card Assembly (CCA) for the Avionics control systems and the majority of the cost in the unit is contributed to the CCAs. On the other hand, the service level driver is not Celestica but rather Jabil, a low volume supplier. As demonstrated in Figure 37, which tracks service level by part number, Jabil is identified as being the supplier that needs the most buffering.

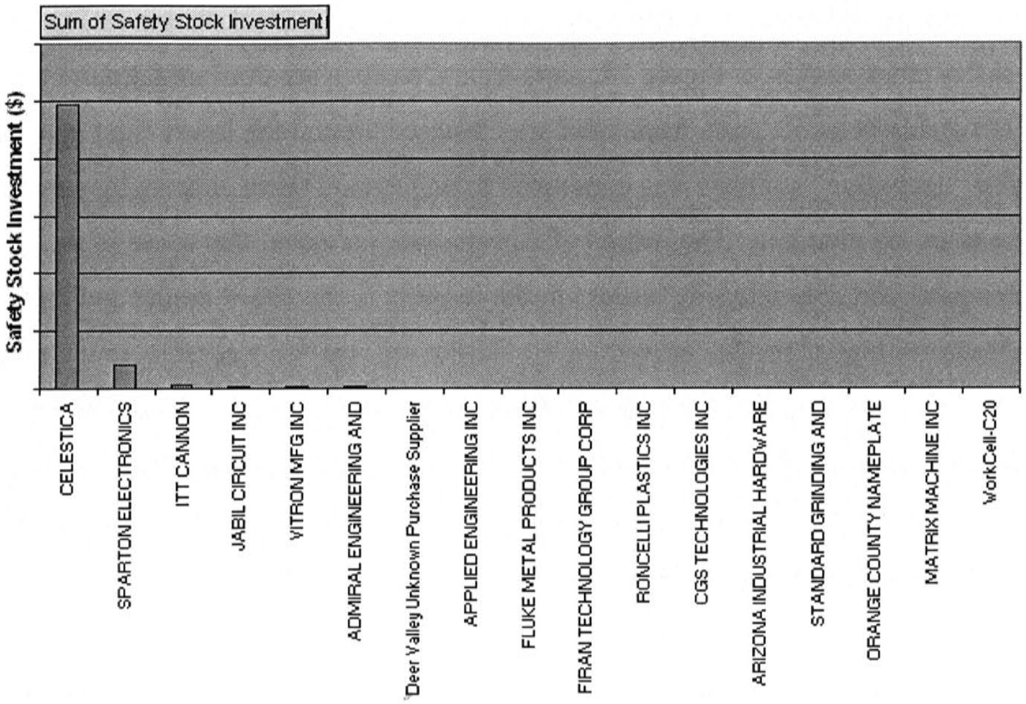


Figure 36: MAU Safety Stock Investment Breakdown by Suppliers

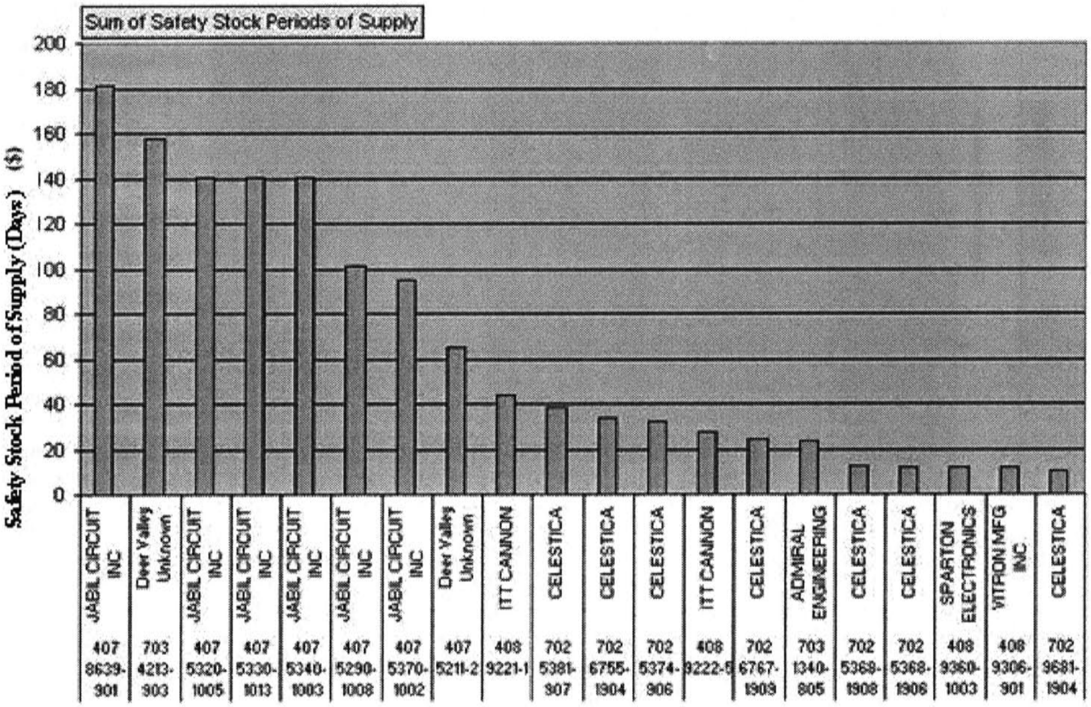


Figure 37: MAU: Safety Stock Service Level Breakdown by Part

The combination of these two drivers is captured in the safety stock matrix in Figure 38. In the safety stock matrix in Figure 38, parts from Celestica are clustered around the upper left quadrant while parts from Jabil are clustered around the lower right quadrant. A similar "deep-dive" analysis was conducted to understand these clusters by consulting with the sourcing planners. The results of this analysis indicated that some of the Celestica parts had data integrity issues similar to parts in the 131-9 model and that the main reason for higher service impact on the Jabil parts was because of its low volume. Since the Jabil parts had so little volume, the model had to recommend holding a single unit of safety stock for a longer period of time before it gets consumed, thereby having an increase on service level. Thus, even though the quantity recommended was only one unit, it was still a major impact from a service level perspective.

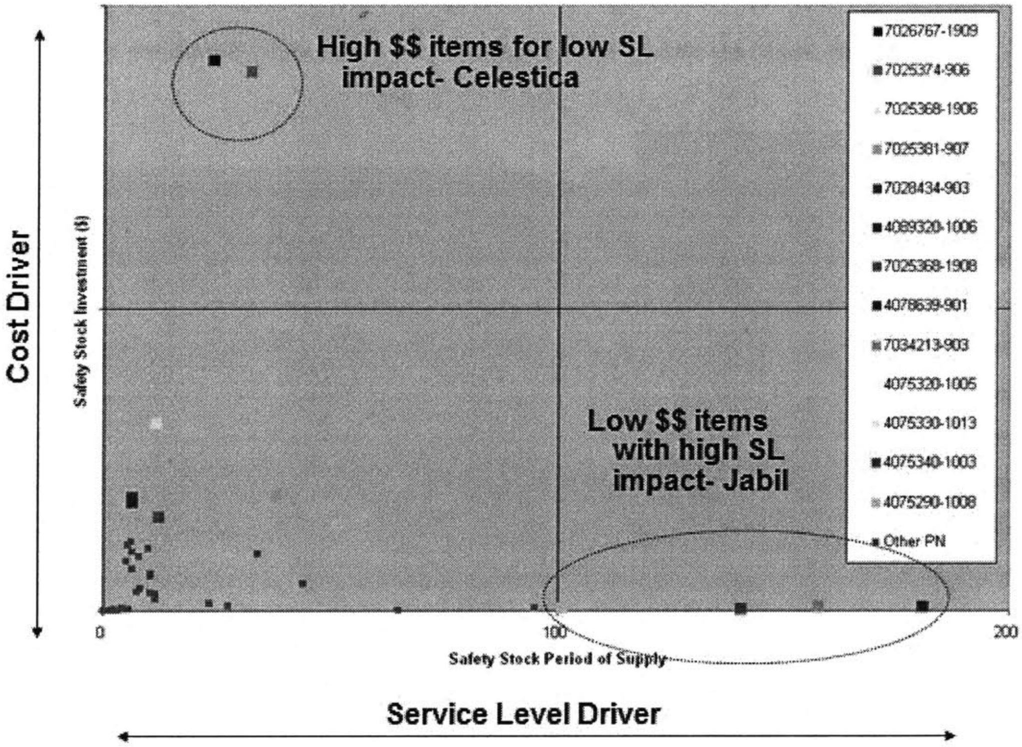


Figure 38: MAU Safety Stock Matrix

Preliminary sensitivity analysis was also conducted to see if the MAU was sensitive to similar inputs as the 131-9 Model. While most of the trends recorded in the analysis were similar to the ones analyzed in the 131-9 Model, the sensitivity on purchase parts lead-time was very different. Figure 39 shows the sensitivity plot of purchase parts lead-time against inventory investment anchored on a current baseline of 100%. As the figure shows, an increase in lead-time will cause inventory investment to increase at a relatively low rate. However, a reduction in lead-time will also cause inventory investment to increase, but at a higher rate. This is because the overall manufacturing lead-time for these end items is less than the customer purchase lead-time. Therefore, if the lead-time for supplier parts is reduced, there will be more inventory waiting to be processed in the warehouse unless the internal system adjusts for the improved lead-time. That is unless Honeywell changes its delivery acceptance and order policy such that parts do not arrive sooner when the lead-time is shortened.

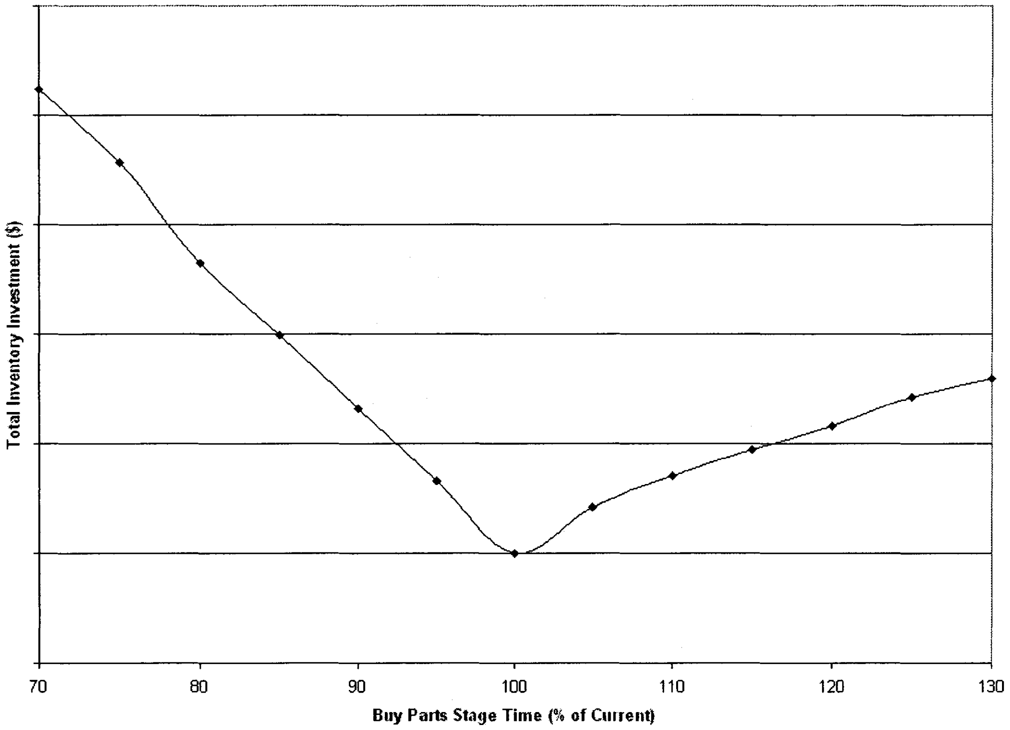


Figure 39: MAU Buy Parts Lead-Time Sensitivity Analysis

5 Conclusion

In conclusion, inventory optimization does provide an innovative solution for determining optimal safety stock locations (nodes) and levels in a complex aerospace supply chain. Contrary to conventional approach of placing safety stock inventory at every stage within the supply chain, strategic inventory can be used on critical stages to satisfying customer demand without incurring significant inventory cost. Users of software like *PowerChain* can design and model a supply chain as a network, in which decisions made within the network can be analyzed as a whole to more easily understand the node-to-node impact. Through this design, companies can then determine the optimal safety stock locations and levels for minimal cost of the safety stock to buffer the variability within the supply chain.

The benefit of this approach goes beyond sheer inventory reduction. It serves as an effective communication tool across the many functional and geographical divisions within a typical supply chain and also enables management to conduct more strategic "what if's scenarios" to estimate the resulting effects.

The two Honeywell supply chains models described in this thesis highlighted both challenges that are unique to the aerospace industry as well as challenges that are similar to other industries. Because of the slower clock speed related to product, process and change in the aerospace industry, benefits will not be as readily apparent after the implementation of this solution. Accordingly, management in this industry will bear a higher responsibility to motivate different divisions to achieve long-term success while balancing expectations of upper management to deliver immediate impact. Furthermore, in order to gain buy-in support from management to use this model as a standard planning tool, it may be necessary to pilot this model in a more stable, predictable supply chain like the Avionics MAU product line first and then transition into a more complex 131-9 supply chain model.

5.1 Future Work

The work described within this thesis is only the initial step of a three-year initiative. While Honeywell has gained a lot of insight into inventory optimization and the associated challenges and sensitivity through this pilot, additional pilots programs will uncover more learning and help improve methodologies using this approach as the standard business practice. As other product centers within Honeywell come up to speed on the data requirements for inventory optimization, Honeywell should continue to march forward with implementing this approach across the board. Additionally, the disruption between OEM and Aftermarket is not clearly understood. While Aftermarket has often been a source of disruption, it has also been a safety net. In the near future, Honeywell should focus on analyzing the various options such as risk pooling to better leverage its internal customer in order to continue to improve operational efficiency and serve its customers.

6 Optiant Glossary

Service Time: The time from which an order is placed until the order is filled, or how much time a particular stage is permitted to fulfill an order to the downstream stage.

Stage Time: Assuming all the raw materials are lined up, it is the time that it takes the raw materials to go through that stage.

Maximum Service Time: Used for Demand Stage only. It is the maximum time that stage is permitted to fulfill an order. It is a constraint to the model optimization

Service Level: The frequency with which demand is met within the Service Time.
- Type I (Fill Rate)
  - The percentage of periods in which no stock-out occurs.
- Type II
  - The percentage of demand for which product was available.

Basestock Inventory & Target
- Basestock Inventory: Inventory physically present at a stage and all other inventory that the stage has ordered and which is en route.
- Basestock Inventory Target: This is the target inventory level that Optiant *PowerChain* generates and can obtain from each stage. It is equal to $\mu t + k\sigma$.
- For each stage, Optiant generates a safety stock target number as well a Basestock inventory target number.

Basestock Policy
- Optiant assumes a BaseStock Policy that is order to a basestock target for each period. This is the policy used to replenish inventory
- Every period (or depending on Review Period), each stage reviews the inventory and orders up to the basestock target
- Before getting inventory replenished, each stage will look at its Inventory at the end of the period, and order so as to cover mean demand for the next period and to ensure that safety stock in the future is equal to SS Target.

Review Periods
- After how many periods, does a stage look at inventory and order up to the target
- Tells us how often do I check for Inventory
- Tells us how often do I decide how much to make (and this triggers how often do I get replenished)
- Tells us how often do we set the schedule on what to make or ship
- When we do build plan, we decide how much to make and that triggers orders for replenishment (raw materials). So build plan frequency can be used as Review Period

Lead-Time: the amount of time from the point at which you determine the need to order to the point at which the inventory is on hand and available for use

Lead-Time Demand

- Forecasted Demand during the lead time period
- This is the average demand
- E.g. if the forecasted demand is 3 units/day and the lead time is 12 days, then lead time demand is 36 units

Replenishment Lead Time (RLT)

- Service Time of previous stage + Stage Time =Replenishment Lead Time
- If you are anywhere in the supply chain, RLT is the total time required from where the stage decided to make a part, until the time that part is made

Net Replenishment Lead Time (NRLT)

- Service Time of previous stage + Stage Time - Service Time for that Stage =Net Replenishment Time
- If NRLT=0, then no SS is required
- Exposure Period is called NRLT

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